DEPARTMENT OF DEFENSE

MILITARILY CRITICAL TECHNOLOGIES

PART III: DEVELOPING CRITICAL TECHNOLOGIES

SECTION 17: SENSORS TECHNOLOGY

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Defense Threat Reduction Agency
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SECTION 17—SENSORS TECHNOLOGY

Highlights

- In modern warfare, the side with superior sensors has a great advantage over its adversaries.

- Active sensors are used to obtain massive amounts of real-time, highly accurate data while passive sensors are used for covert-type operations.

- Improved sensor performance is required for offsetting or countering the stealthy targets being introduced worldwide.

- Sensor performance can be improved by:

    – Multiple, unique interference-rejection techniques.

    – Automated information management, including using more robust discrimination and correct decisions criteria.

    – Fusion of data from multiple looks and sources, including using network-centric warfare techniques.

- It is envisioned that evolutionary improvements in sensors will continue, but at an accelerated pace.

- Nuclear, chemical residue, and hyperfine interactions technologies [nuclear quadrupole resonance (NQR)] are being used to correctly identify explosives in buried land mines.

OVERVIEW

This section includes the technologies for acoustic and electro-optic sensors and radar, the primary sensors of military interest. Laser sensors are included in the Lasers, Optics, and Supporting Technology section. Gravity and magnetic sensors are included in Positioning, Navigation, and Time section. Inertial, chemical, biological, and nuclear sensors are covered in their respective sections. This section also covers the technologies for the mine detection, minefield detection, and neutralization aspects of countermining.

Acoustic and electro-optic sensors, radar, and countermining are already vital and will become even more so in the future for effective and safe military operations, regardless of whether for open conflict, peacekeeping, training, or humanitarian efforts. Most of the major sensors are also vital for many civilian endeavors as well. It is envisioned that evolutionary improvements in sensors will continue, but at an accelerated pace.

No single sensor approach has been demonstrated to be effective in finding buried mines. The fusion of ground-penetrating radars (GPR), electromagnetic induction (EMI) technologies, and nuclear detection techniques shows great promise for improved target detection with fewer false alarms.

RATIONALE

The data obtained from sensors is a basic ingredient for all military operational concepts in use now and projected for the future. Military sensors are vital to operations at both the tactical and strategic levels. They are needed to provide information during all phases of planning and operations and during all circumstances where ranges exceed visual capabilities. In modern warfare, the side with the superior sensors has a significant advantage over its adversaries.

BACKGROUND

The data obtained from these primary sensors is a basic and necessary ingredient for all military planning and operations. In most warfare scenarios, sensors will be used singly or in combinations, with some serving as primary and others used to confirm or verify the results. Active sensors are used to obtain massive amounts of real-time, highly accurate data. Passive sensors are used for covert-type operations.

Military uses of acoustic sensors on land include intruder detection and detection and location of target vehicles and direct-fire weapons. They are also used in airborne munitions to passively detect, identify, and locate noise-radiating targets. Civilian applications on land are intruder-detection alarms and the location and identification of petroleum-producing features in Earth's crust. Military uses of acoustic sensors in the marine environment include locating ships, submarines, torpedoes, ocean mines, and objects lost at sea; and weapons homing and activation. Civilian applications are fish finding, geophysical exploration at sea, and petroleum and mineral exploitation.

Electro-optical sensors are typically used in night-vision devices by both civilian and military sectors. Military uses include terminal guidance for smart weapons.

For the military, radar is used on all types of platforms and fixed sites for detecting and locating targets, for weapon guidance, and to obtain information about Earth features and atmospheric conditions. It is similarly used in civilian applications for traffic control on land, in the air, and on the seas and for weather tracking.

Countermining is required to detect and neutralize land mines and minefields in a rapid and safe manner.

TECHNOLOGY ASSESSMENT

A greater variety of more sensitive and affordable sensors is expected to be required as more and more accurate data are sought for both automated and manual decision making in the civilian and military sectors. Although the sensors covered have widely dispersed functions, they have the common characteristic that the U.S. state of the art throughout the cold war has been comparable to or better than the rest of the world. The U.S. lead in sensors has been driven by its military objectives. Unfortunately, the U.S. military advantage is now eroding with declining budgets, while sensors need continued improvements to counter new, stealthy targets and counter-measures. The situation will be compounded when more and more sensors are developed and perfected by world-wide industry as the full impact of the information age is realized and exploited.

WORLDWIDE TECHNOLOGY ASSESSMENT

The United States has clearly led in the development, production, and use of acoustics and electro-optic sensors and radar. The former Soviet Union (FSU) was very active in all areas of sensor development, but rarely reached the technological level of the West. Current Russian sensors remain limited by the lack of production facilities and a motivated work force. Where there is a national priority, France, Germany, Japan, and the UK have developed and produced excellent sensors. These and some other countries are making good progress in catching up. The former substantial lead of the United States in acoustic systems has eroded to a marginal lead over Russia, France, and the UK. Germany and Japan come next, followed by Australia and Canada. The United States clearly leads in cooled staring and uncooled focal plane arrays for thermal imaging, followed by the UK, France, Japan, and

Germany. The United States is also the world leader in third-generation image intensifiers, followed by Russia. The Netherlands continues to develop and use second-generation devices. China and India have a first- and second-generation capability, but it is based on know-how imported from the West. Little development is evident. Further development of image-intensification technology in the United States has slowed in favor of solid-state sensors. The United States continues to lead in radar development, but faces stiff worldwide competition, particularly in the area of synthetic aperture radars (SAR). Countries developing and marketing excellent high-resolution SARs include the UK (Racal), Germany (Dornier), Israel (Elta), and France (Thomson CSF). In the area of foliage-penetration systems, Sweden has led research efforts with its Carabas system. In some of the developing technologies, such as space-based moving target indication radar, the United States leads, but has cooperative research and information exchange agreements with the UK and Canada. In other areas (e.g., stealth radar) the United States has a commanding lead, but countries such as France and China are investing significant research resources.
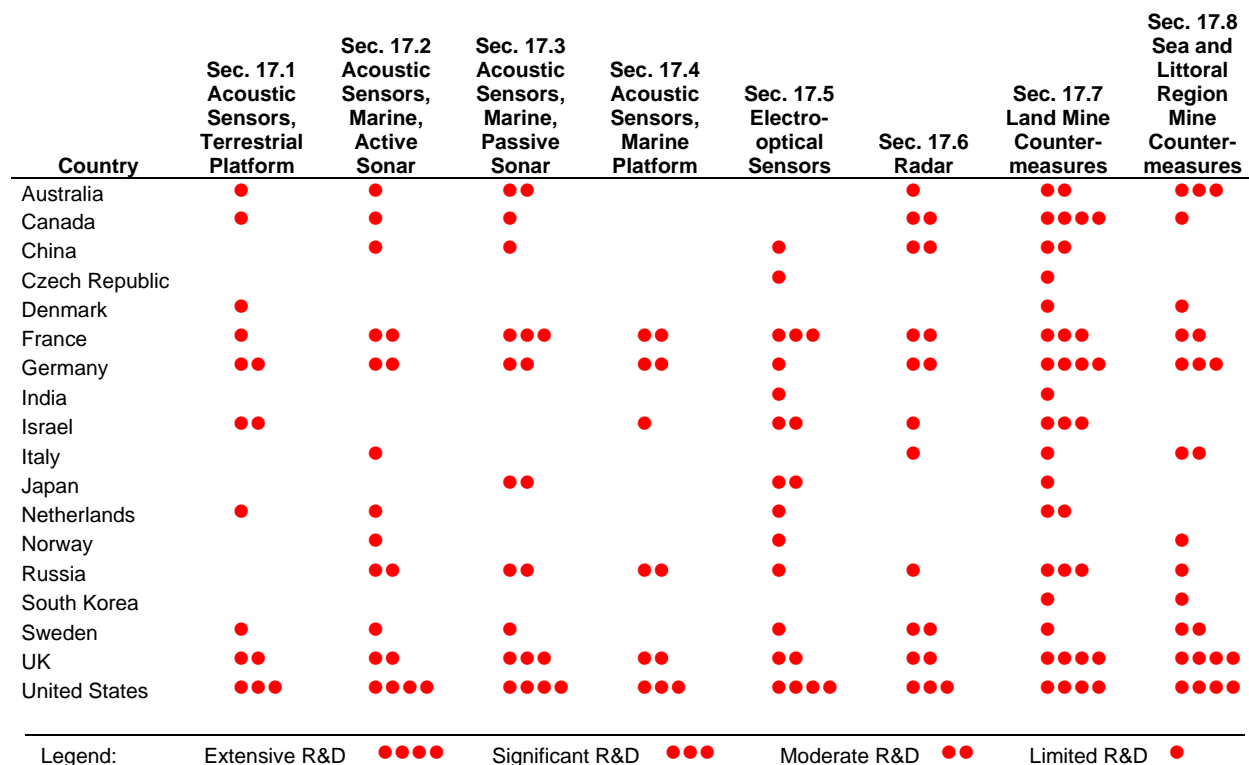
Country	Sec. 17.1 Acoustic Sensors, Terrestrial Platform	Sec. 17.2 Acoustic Sensors, Marine, Active Sonar	Sec. 17.3 Acoustic Sensors, Marine, Passive Sonar	Sec. 17.4 Acoustic Sensors, Marine Platform	Sec. 17.5 Electro-optical Sensors	Sec. 17.6 Radar	Sec. 17.7 Land Mine Counter-measures	Sec. 17.8 Sea and Littoral Region Mine Counter-measures
Australia	●	●	●●			●	●●	●●●
Canada	●	●	●			●●	●●●●	●
China		●	●		●	●●	●●	
Czech Republic					●		●	
Denmark	●						●	●
France	●	●●	●●●	●●	●●●	●●	●●●	●●
Germany	●●	●●	●●	●●	●	●●	●●●●	●●●
India					●		●	
Israel	●●			●	●●	●	●●●	
Italy		●				●	●	●●
Japan			●●		●●		●	
Netherlands	●	●			●		●●	
Norway		●			●			●
Russia		●●	●●	●●		●	●●●	●
South Korea							●	●
Sweden	●	●	●		●	●●	●	●●
UK	●●	●●	●●●	●●	●●	●●	●●●●	●●●●
United States	●●●	●●●●	●●●●	●●●	●●●●	●●●	●●●●	●●●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

Figure 17.0-1. Sensors Technology WTA Summary

SECTION 17.1—ACOUSTIC SENSORS, TERRESTRIAL PLATFORM

Highlights

- Acoustic is the sensor of choice for noise-emitting still and moving targets that are out of the line of sight in a battlefield.

- Acoustic sensors provide effective detection and tracking of noise-emitting targets for battlefield monitoring and targeting.

- Acoustics sensors are typically primary in network of unattended ground sensors (UGS).

- Acoustic sensors provide improved identification and tracking of targets in loud acoustic clutter while rejecting false targets.

- It is envisioned that evolutionary improvements in acoustics will continue, but at an accelerated rate.

OVERVIEW

This subsection covers technologies for the development or production of acoustic systems for terrestrial (land-based) applications. Military applications include passive sensors contained in airborne munitions that are used for detecting, identifying, locating, and homing on noise-radiating targets on the ground. Ground-based, passive acoustic systems for the detection and location of noise-radiating targets, such as intruders, vehicles, and direct-fire weapons are included.

Microphones or geophones are placed for the best reception and maximum received signal-to-noise ratio (SNR). The criterion for decision making and the selection and weighting of discriminating clues is of paramount importance for these systems. For most of these applications, omnidirectional microphone arrays are also required.

Ground vehicles used for the passive reception platform can generate an acoustic environment much louder than the signals to be detected. Self-noise reduction, including but not limited to isolation, is required.

Civilian application includes seismic acoustic systems for locating and identifying petroleum-producing features within Earth's crust. (The Information Technology section discusses the processing and computational capabilities of seismic land-based processing centers that are considered critical.)

Evolutionary, emerging technology developments are highlighted in the following data sheets. There are no known revolutionary emerging developments underway.

RATIONALE

Passive acoustic sensors in airborne munitions provide a low-cost, nonalerting detection, identification, and location system for targeting noise-generating target vehicles that are out of the line of sight. Passive acoustic systems for intruder detection and location, a current military technique, has a growing number of commercial applications. The unique processing used to discriminate against false targets and identify intruders is specially developed for this application and considered militarily critical. Development of passive acoustic systems to detect and locate target vehicles and direct-fire weapons at distances of up to 5,000 m while the detection sensors operate in a noisy acoustic environment is a highly specialized and militarily critical capability that has no commercial counterpart.

The signal-processing and digital-computing capability of seismic land-based processing centers is similar to (and can be used for) antisubmarine warfare (ASW) passive sonar data analysis. U.S. industry has dominated seismic processing and computational development.

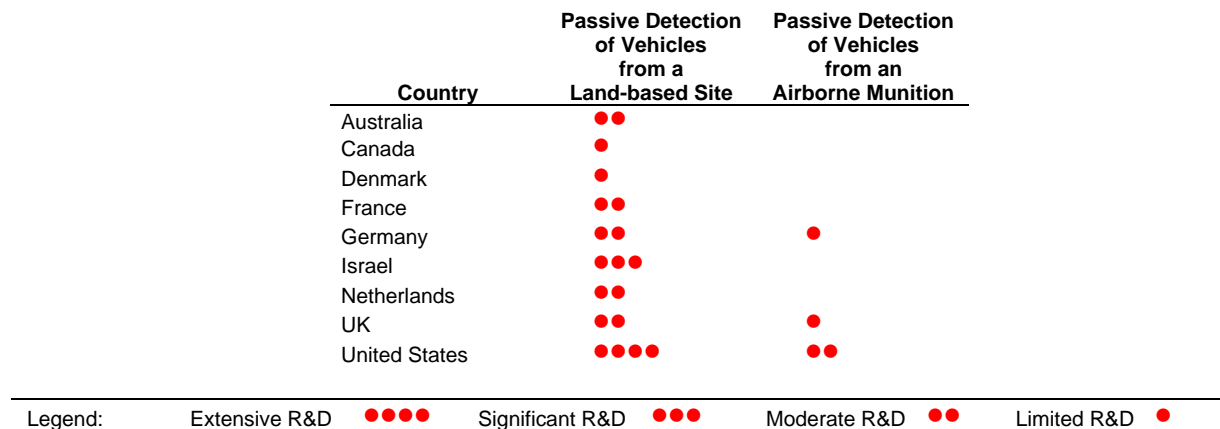| Country	Passive Detection of Vehicles from a Land-based Site	Passive Detection of Vehicles from an Airborne Munition
Australia	●●	
Canada	●	
Denmark	●	
France	●●	
Germany	●●	●
Israel	●●●	
Netherlands	●●	
UK	●●	●
United States	●●●●	●●

Legend:　　Extensive R&D ●●●●　　Significant R&D ●●●　　Moderate R&D ●●　　Limited R&D ●

Figure 17.1-1. Acoustic Sensors, Terrestrial Platform Technology Systems WTA Summary

Terrestrial acoustic intruder-detection systems are now being developed commercially as well as by the military. Israel has an advanced intruder-detection system. The U.S. military has pioneered the development and use of passive acoustic systems to detect and locate target vehicles and direct-fire weapons. U.S. industry has dominated the worldwide development and use of seismic data-processing and analysis.

Various technologically advanced countries have recently developed UGS. Air deployed or hand emplaced, UGSs consist of various passive, low-cost, small sensor technologies for robust, short-range detection, identification, localization, and tracking of ground and airborne targets. These expendable UGS consist of acoustic and seismic as the primary sensors. Coupled with short-haul communication, they are deployed in mass quantities to crate a web of networked sensors for area surveillance and situational awareness.

LIST OF TECHNOLOGY DATASHEETS
III-17.1. ACOUSTIC SENSORS, TERRESTRIAL PLATFORM

DATA SHEET III-17.1. PASSIVE DETECTION OF VEHICLES FROM A LAND-BASED SITE

Developing Critical Technology Parameter	Detecting, identifying, and real-time tracking from a land-based site of noise-emitting, moving target vehicles that are out of the line of sight in a battlefield.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	For air-deployable, all-weather sensors.
Unique Software	Validated set of algorithms that provides the knowledge base for identifying potential targets, discriminating against false targets, and providing real-time tracking of moving targets.
Technical Issues	Implementing the processes that discriminate between noise-emitting targets and nontargets in a battlefield and the real-time tracking of moving targets to within 10 m at 5,000-m range. Also required is quieting of support equipment that otherwise can generate an acoustic environment that is much louder than the signals to be detected.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

The importance of ground-based, passive acoustic-detection systems is based on two requirements: (1) real-time battlefield monitoring and (2) real-time detection, identification, tracking, and targeting of mobile, noise-emitting targets in the battlefield. The strategic importance is based on the battlefield being out of the line of sight and not capable of being monitored by other battlefield sensors. This land battlefield-monitoring capability will provide a direct contribution to the Joint Vision 2010 operational concepts of dominant maneuver and full-dimensional protection. The capability for real-time tracking of noise-emitting targets is a direct contribution to precision engagement.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	Canada	●	Denmark	●	France	●●
Germany	●●	Israel	●●●	Netherlands	●●	UK	●●
United States	●●●●						

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The United States leads in real-time, passive detection of noise-generating vehicles in a battlefield. Israel has an advanced intruder-detection system that has some similar characteristics. No other development is known. Advanced passive detection of noise-emitting targets is driven by military applications.

DATA SHEET III-17.1. PASSIVE DETECTION OF VEHICLES FROM AN AIRBORNE MUNITION

Developing Critical Technology Parameter	From an airborne munition, detecting, identifying, and real-time tracking of noise-emitting stationary and moving target vehicles that are out of the line of sight in a battlefield.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	All-weather, airflow-noise-resistant acoustic sensors.
Unique Software	Validated set of algorithms that provides the knowledge base for identifying potential targets, discriminating against false targets, and real-time tracking of moving targets.
Technical Issues	Implementing within an airborne munition the processes that discriminate between noise-emitting targets and nontargets in a battlefield, locate a target, and then track the moving target to within 5 m at up to 5,000-m range. Discrimination is required against the airborne munition airflow.
Major Commercial Applications	None identified.
Affordability	The cost of expendable munitions is always a factor.

RATIONALE

The importance of passive acoustic-detection systems within airborne munitions stems from the need to hit, with high probability, potentially moving targets that are (1) beyond the line of sight and (2) not targetable by other battlefield sensors. The targeting from an airborne munition of a noise-emitting mobile target that is out of the line of sight will provide a direct contribution to the Joint Vision 2010 operational concept of precision engagement.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●	UK	●	United States	●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The United States leads in passive detection from an airborne munition of still or moving noise-generating targets in a battlefield. Germany and the UK have limited developments underway. No other developments are known.

SECTION 17.2—ACOUSTIC SENSORS, MARINE, ACTIVE SONAR

Highlights

- Active sonar systems provide rapid and accurate target location for developing a quick-response fire-control solution.

- Major improvements in active sonar systems are necessary to counter the more limiting environmental acoustic conditions found in littoral areas.

- A higher ratio of correct decisions to false alarms is to be achieved for littoral areas by improving computer-aided detection, classification, and information management.

- Major operational improvements are to be achieved by increasing reverberation and countermeasure interference-rejection techniques.

- Received signal-to-noise levels are to be enhanced by data fusion from multiple platforms and adaptive processing to better match sonar to the acoustic environment.

- Active sonar for weapons systems is being improved to operate at high speed and resolve, identify, and successfully track small, slow, diesel-electric submarine targets in the adverse shallow-water environment.

- It is envisioned that evolutionary improvements in active sonars will continue, but at an accelerated pace.

OVERVIEW

This subsection covers the technologies for the development and production of active sonars, which employ acoustic signals to echo range and locate underwater objects and to determine features in Earth's crust. Military uses for active sonars include ASW and antiship warfare, weapon homing, torpedo defense, mine warfare, swimmer warfare, deep-sea salvage, and underwater communication and navigation. Commercial uses include locating fish and other objects underwater, seismic exploration at sea, petroleum and mineral exploitation, and academic studies. Dual use includes the detection, classification, and tracking of underwater objects and features for determining bottom depth and mapping and for navigation.

Active sonar performance is highly dependent on the acoustic environment and frequency of the system. The most common propagation paths are direct, bottom bounce, and convergence zone. The major limit is the interference from reverberation, which is created by the backscatter of the transmitted signal as it passes through the ocean medium or is reflected back from the ocean boundaries. Reverberation has near-zero Doppler and thus creates many false alarms and interferes most when tracking slow-speed targets that cannot be separated from the reverberation by doppler processing. Propagation loss in the ocean is frequency dependent, and lower frequencies have been selected to gain longer ranges. Antiship and antisubmarine sonars operate in the 100-Hz to 10-kHz frequency band to obtain long ranges out to 30 km. In the shallow water of the littorals, the convergence zone path does not exist and detection ranges are significantly shorter. Mine-detection sonars operate in the 30- to 100-kHz band to have increased resolution, but as a consequence have shorter ranges of up to 2,000 m. To obtain the resolution required to discriminate and identify small targets or features from background clutter, mine classification, bottom mapping, and deep-sea salvage sonars operate in the 60-kHz to 750-kHz frequency band and have ranges out to a few hundred meters. The active sonar in underwater weapons operates in the 15- to 60-kHz band and has ranges on the order of 1,000 m to detect, locate, and track the target and provide steering commands. Marine seismic survey systems use a towed 8- to 200-Hz source and a long, towed hydrophone array to receive the signals bounced off the features deep in Earth's crust. By this process, these systems can locate areas that have potential for producing petroleum products.

Obviously, there is a sizable amount of overlap between the civilian and military applications. Navy sonars operate monostatically or multistatically from a variety of ships, submarines, and aircraft; from moored or bottom-

mounted locations; and in all environments. Most active sonar developments have been driven by military use. Civilian sonars are a small but growing part of the active sonar market. Most have dual-use potential for military application.

There are important evolutionary, emerging developments in the following data sheets. There are no known revolutionary, emerging technology developments underway.

RATIONALE

The strategic importance of active sonar for ASW has continued to increase with the worldwide increased emphasis on littoral versus deep-ocean warfare and the proliferation of quiet diesel-electric submarines. Faced with quieter submarine targets or an acoustically cluttered environment, active sonar becomes the sensor of choice. Active sonar is also the primary sensor once an operational engagement commences. Active sonar performance is being enhanced as better performance prediction allows selection of the most effective operating mode and more computational capability is added and used to reduce the false-alarm rate. Active sonars will also be more effective in the future as systems are mounted on several different platforms and are networked together (network-centric warfare). Active sonars remain the most effective sensor for detecting, locating, and tracking sea mines, torpedoes, and swimmers and for the homing and activation of acoustic mines and torpedoes.

WORLDWIDE TECHNOLOGY ASSESSMENT

Country	Advanced Data Processing for Active Sonar	Active Sonar Signal and Data Processing for Multiplatforms	Reverberation Suppression for Active Sonar	Channel-Adaptive Processing for Active Sonar	Environmentally Adaptive Active Sonar	Advanced Active Sonar for Submersibles
Australia	●●					
Canada	●●					
China	●					
France	●●●	●●	●●	●	●●	
Germany	●●					
Italy	●					
Japan	●●	●	●		●	
Netherlands	●					
Norway	●					
Russia	●●	●				
Sweden	●					
UK	●●●	●●	●●	●	●●	
United States	●●●●	●●●●	●●●	●●●	●●●	●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

(Continued)

Figure 17.2-1. Acoustic Sensors, Marine, Active Sonar Systems WTA Summary

Country	Submarine Ahead-Looking Active Sonar	Multi-Aspect Data Fusion Processing for Active Sonar	Active Sonar for Underwater Weapons	Active Sonar for Mine Counter-measures	Active Sonar for Anti-Torpedo Torpedoes
Australia					
Canada					
China					
France			●●●	●●	●●
Germany			●●●	●●	●
Italy			●●		
Japan			●●	●●	
Netherlands					
Norway					
Russia			●●●	●●	●●
Sweden			●●		
UK			●●●	●●	●●
United States	●●	●●	●●●●	●●●●	●●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

Figure 17.2-1. Acoustic Sensors, Marine, Active Sonar Systems WTA Summary (Cont'd)

The United States lead in active sonar development is now only marginal over Russia and the major western producing countries. France and the UK clearly pace the remainder of the western world and, though smaller in size, still lead Russia in many technology areas. Germany and Japan come next, followed by Australia and Canada. All of the above countries have a reasonably complete capability in acoustic sensors and weapons, largely sustained by competent laboratories and industry. Japan obtained a large part of its capability by licensing arrangements with the United States. Italy, the Netherlands, Norway, and Sweden have acoustics capabilities in limited niche areas. Other countries that produce active sonars have a very limited capability.

LIST OF TECHNOLOGY DATASHEETS
III-17.2. ACOUSTIC SENSORS, MARINE, ACTIVE SONAR

DATA SHEET III-17.2. ADVANCED DATA PROCESSING FOR ACTIVE SONAR

Developing Critical Technology Parameter	Automated or computer-aided detection, tracking, classification, and identification of undersea-warfare (USW) targets in littoral areas or cluttered acoustic environments using empirically validated clues (discriminates), decision criteria, and decision processes.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) identifying and selecting clues that highlight potential targets and discriminate against false targets, (2) implementing the discrimination process, (3) developing the decision criteria, and (4) for normalizing and thresholding the acoustic signals. These sets of algorithms are for the functions of detection, classification, and identification of targets and target-like false targets.
Technical Issues	Identifying and selecting the weighting of clues that discriminate between USW targets and nontargets and selecting and implementing the decision processes that combined yield a 95-percent probability of detection and classification with a false-alarm rate of less than 5 percent. This is a unique military application and is constrained by the difficulty of obtaining realistic and representative data at sea and perfecting the series of processes.
Major Commercial Applications	Fish, swimmer, and other object-detection sonar systems.
Affordability	The cost of sea tests to obtain realistic target and target-like false target data in a variety of environments is a limiting factor.

RATIONALE

The strategic importance of active sonar for ASW has continued to increase with the worldwide emphasis on littoral versus deep-ocean warfare and the proliferation of quiet diesel-electric submarines. Faced with quiet submarines in an acoustically cluttered environment, active sonar becomes the sensor of choice. Active sonar is mandatory once an operational engagement commences; however, it is hampered by reverberation interference, low signal strength received, low probability of correct decisions, high false-alarm rate, and operator overload. Advanced data processing has the potential for substantially improving probability of correct decisions and actions, as well as reducing the false-alarm rate and operator overload.

Active sonar remains the most effective sensor for detecting, locating, and tracking sea mines, torpedoes, and swimmers and for the homing and activation of acoustic mines and torpedoes. Advanced data processing is vital to the future success of these functions as well.

The added capability of the combined technologies of computer-aided detection, tracking, classification, and identification of undersea targets in harsh acoustical environments will aid USW forces executing the Joint Vision 2010 operational concepts of precision engagement, dominant maneuver, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	Canada	●●	China	●	France	●●●
Germany	●●	Italy	●	Japan	●●	Netherlands	●
Norway	●	Russia	●●	Sweden	●	UK	●●●
United States	●●●●						

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

The United States continues to lead in real-time, automated, or computer-assisted data processing for active sonars. France and the UK still lead Russia and outpace the rest of the world. Germany and Japan are next. Australia, Canada, Italy, Netherlands, Norway, and Sweden have advanced data processing in niche areas. Other countries that produce or use active sonars have a very limited advanced data-processing capability. Advanced sonar data processing is driven by military applications.

DATA SHEET III-17.2. ACTIVE SONAR SIGNAL AND DATA PROCESSING FOR MULTIPLATFORMS

Developing Critical Technology Parameter	Real-time processing of acoustic data for fixed, deployed, or mobile arrays operated in the bistatic or multistatic mode to increase target ranges and probability of correct decisions.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Bistatic or multistatic platforms at sea for collection of data.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for synchronizing and normalizing multiple incoming signals, adjusting the dynamic range of multiple incoming signals, and performing data fusion.
Technical Issues	Synchronizing and normalizing the multiple incoming signals, adjusting the dynamic range for very weak to very strong signals, and performing data fusion such that there is a signal gain of up to 50 percent over that of a single receiver.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests with multiple platforms to obtain realistic target and target-like false-target data in a variety of environments is a limiting factor.

RATIONALE

The strategic importance of active sonar for ASW has continued to increase with the worldwide emphasis on littoral versus deep-ocean warfare and the proliferation of quiet diesel-electric submarines. Faced with quiet submarines in an acoustically cluttered environment, active sonar becomes the sensor of choice. Active sonar is mandatory once an operational engagement commences; however, active sonar is hampered by reverberation interference, low signal strength received, low probability of correct decisions, high false-alarm rate, and operator overload. Data fusion of advanced signal and data processing from multiple platforms has the potential for increasing the combined target signal levels by 50 percent, thereby extending operating range, improving probability of correct decisions and actions, and reducing the false-alarm rate. Data fusion among multiple sensor platforms will be aided by the emerging network-centric techniques.

The added capability of real-time processing for active sonars from multiplatforms will aid ASW forces executing the Joint Vision 2010 operational concepts of precision engagement, dominant maneuver, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Japan	●	Russia	●	UK	●●
United States	●●●						

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States leads in data fusion of signals received from multiple platforms. France, Russia, the UK, and possibly Japan are exploring multiplatform processing. No other country is known to be developing this capability. Advanced data fusion is driven by military applications.

DATA SHEET III-17.2. REVERBERATION SUPPRESSION FOR ACTIVE SONAR

Developing Critical Technology Parameter	Real-time tracking of submarine targets with speeds less than 3 knots that are obscured by reverberation or acoustic countermeasures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real-time, dynamically (1) identifying and selecting transmit pulse type, coding, length, frequency, and frequency agility that minimize the interference received with the variations being based on the reverberation and countermeasure interference being received; (2) normalizing the incoming signals; and (3) adjusting the receiver dynamic range for very weak incoming signals in the presence of very strong reverberation or countermeasures.
Technical Issues	Dynamically and in real-time: (1) select and vary transmit pulse type, coding, length, frequency, and frequency agility to minimize the interference with the variations being based on the reverberation or countermeasure signals being received; (2) normalize the incoming signals; and (3) adjust the dynamic range for very weak incoming signals in the presence of very strong reverberations or countermeasures.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain realistic target and target-like false target data in a variety of reverberation fields and countermeasures is a limiting factor.

RATIONALE

The strategic importance of active sonar for ASW has continued to increase with the worldwide emphasis on littoral versus deep-ocean warfare and the proliferation of quiet diesel-electric submarines. Faced with quiet submarines in an acoustically cluttered environment, active sonar becomes the sensor of choice. Active sonar is mandatory once an operational engagement commences; however, active sonar is hampered by interference from reverberation, low signal strength received, low probability of correct decisions, high false-alarm rate, and operator overload. The capability to dynamically adjust the transmit signals in real time to reduce the blinding effect of reverberation and countermeasures has the potential to increase by up to 100 percent the probability of detection and classification of targets moving at speeds less than 3 knots or in the presence of countermeasures. Submarines operating in the littorals will tend to hide on the bottom or move slowly while on reconnaissance or waiting for an engagement. The reverberation received by an active sonar receiver is centered on 0 knots Doppler, and targets moving at speeds of over 3 knots can be separated from the reverberation using narrowband digital filtering. Sonar countermeasure or jamming signals can vary in every parameter and are designed to acoustically blind and confuse the operator. The blinding effect and confusion is best offset by the capability to dynamically adjust in real time the transmitting signal and receiver characteristics used to process targets while rejecting the interference.

The added capability of reverberation suppression for active sonar will aid ASW forces executing the Joint Vision 2010 operational concepts of precision engagement, dominant maneuver, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Japan	●	UK	●●	United States	●●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

    The United States leads in dynamically adjusting transmit and receive characteristics to suppress interference from reverberation or acoustic countermeasures. France, the UK, and possibly Japan are exploring this capability. No other country is known to be involved. This capability is driven by military applications.

DATA SHEET III-17.2. CHANNEL-ADAPTIVE PROCESSING
FOR ACTIVE SONAR

Developing Critical Technology Parameter	Channel-adaptive processing using a probe pulse to characterize the medium and optimize the propagation paths being utilized, thereby increasing signal strength and reliable data rate.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for dynamically identifying and selecting transmit and receive parameters in real time, as a means to optimize the propagation path utilized. The parameter selections are based on information extracted from the signals returned from the probe pulse.
Technical Issues	(1) Real-time, dynamic identification and selection of transmit and receive parameters required to optimize the propagation path being utilized, with the parameter selections based on information extracted from the signals returned from a probe pulse.
	(2) Capability to maintain the probe pulse coherency from pulse to pulse to maintain sufficient signal strength for extracting the information that characterizes the medium.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain sufficient data in a variety of environmental acoustic conditions to formulate the dynamic database is a limiting factor.

RATIONALE

The ability to acoustically communicate between aircraft or surface ships and submarines is vital for multi-platform operations. Long-range, underwater acoustic communications are often a subset of the active sonar system. The range of operation is seriously limited by environmental acoustic conditions. The capability to dynamically adjust the transmit and receive parameters in real time to match the optimum propagation path has the potential for increasing reliable data rate by over 500 percent. This improvement will be most pronounced for littoral areas. Such improvements are especially needed for submarine network-centric capability.

The added capability of channel-adaptive processing for active sonar will be a major contribution to enhancing underwater communications, which is vital for ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●	UK	●	United States	●●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States leads in developing this capability. France and the UK are exploring the capability. No other country is known to be involved. This capability is driven by military applications.

DATA SHEET III-17.2. ENVIRONMENTALLY ADAPTIVE ACTIVE SONAR

Developing Critical Technology Parameter	Dynamically matching transmit parameters to environmental acoustic conditions to minimize multiple arrival of signals that interfere with each other and reduce the signal strength received.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for dynamically selecting and varying, in real time, the transmit parameters pulse length, frequency, and depression angle to minimize the interference from multiple arrivals. The parameter variations are based on historical data and in situ measurements of environmental acoustic conditions such as water depth, water column temperatures, bottom characteristics, and layer depth.
Technical Issues	(1) Dynamically selecting and varying, in real time, the transmit parameters pulse length, frequency, and depression angle to minimize the interference from multiple arrivals, with the parameter variations based on historical data and in situ measurements of environmental acoustic conditions such as water depth, water column temperatures, bottom characteristics, and layer depth.
	(2) Affordable, in situ sensors that do not restrict the operation of the sensor platform.
	(3) Environmental acoustic data that characterizes the propagation paths for operational areas.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain sufficient data in a variety of environmental acoustic conditions to formulate the dynamic database is a limiting factor. Cost of expendable, in situ sensors is an affordability issue.

RATIONALE

The strategic importance of active sonar for ASW has continued to increase with the worldwide emphasis on littoral versus deep-ocean warfare and the proliferation of quiet diesel-electric submarines. Faced with quiet submarines in an acoustically cluttered environment, active sonar becomes the sensor of choice. Active sonar is mandatory once an operational engagement commences; however, active sonar is hampered by reverberation interference, low signal strength received, low probability of correct decisions, high false-alarm rate, and operator overload. The capability to dynamically adjust the transmit parameters in real time has the potential for reducing the multipath interference and thereby increase signal strength by over 20 dB. The potential for interference reduction is greatest in littoral operating areas.

The added capability of environmentally adaptive active sonars will aid ASW forces executing the Joint Vision 2010 operational concepts of precision engagement, dominant maneuver, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Japan	●	UK	●●	United States	●●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States leads in the capability to dynamically adjust the transmit parameters. France, the UK, and possibly Japan are exploring this capability. No other country is known to be involved. This capability is driven by military applications.

DATA SHEET III-17.2. ADVANCED ACTIVE SONAR FOR SUBMERSIBLES

Developing Critical Technology Parameter	Submersible active sonar having feature height finding or beam interpolation, computer-aided detection and track, and fine-angle horizontal and vertical resolution for small object location and recovery and navigation in restricted areas.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Validated set of algorithms for real-time height finding, beam interpolation, and reducing bottom backscatter interference.
Technical Issues	Feature height finding, beam interpolation, computer-aided detection and track, and fine-angle horizontal and vertical resolution.
Major Commercial Applications	Submersible object location and recovery sonar, obstacle avoidance, feature height finding, and navigation in restricted areas.
Affordability	None identified.

RATIONALE

For submersibles, active sonar is a valuable asset for safely navigating in close-in, uncharted areas and for locating objects while operating near the sea floor or other obstacles. The use of active sonar in these environments, however, is generally hampered by bottom reverberation, cluttered and confusing returns, low resolution and accuracy, and operator overload. This advanced, high-resolution sonar for submersibles has the potential for providing accurate information that aids in detecting, identifying, and accurately locating small objects, as well as for determining the height of targets or bottom features that are ahead of the craft. The added capability of high-resolution-feature height finding and navigation for submersibles will provide a significant contribution to the rapid location and recovery of high-value munitions lost at sea, which supports the Joint Vision 2010 operational concept of full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

No other country is known to be developing this capability. The capability is driven by military applications.

DATA SHEET III-17.2. SUBMARINE AHEAD-LOOKING ACTIVE SONAR

Developing Critical Technology Parameter	Ahead-looking, bathymetric active sonar for submarines using monopulse (interferometric) processing and providing system accuracies better than 0.5 percent of the average water depth (below the platform or above the platform for an ice canopy) across the swath and having the information displayed with 3–D qualities.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Validated set of algorithms for real-time, monopulse interferometric processing.
Technical Issues	Monopulse interferometric processing and an intuitive visualization display that provides 3–D qualities.
Major Commercial Applications	Submersible precision navigation and obstacle location.
Affordability	None identified.

RATIONALE

Active sonar is a valuable asset for submarines to safely navigate in close-in uncharted areas, for operating near the sea floor or ice canopies, or for generating charts of these type of areas. The use of active sonar in these environments, however, is hampered by reverberation, cluttered and confusing returns, low resolution and accuracy, and operator overload. Data obtained from multiple aspects will be suitable for developing navigation charts.

The added capability of high-resolution submarine navigation will provide a significant contribution for operating in littorals and other cluttered undersea areas, which supports the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

No other country is known to be developing this capability, which capability is driven by military applications.

DATA SHEET III-17.2. MULTI-ASPECT DATA FUSION PROCESSING FOR ACTIVE SONAR

Developing Critical Technology Parameter	Multi-aspect data fusion processing for submarines and submersibles that provides increased resolution and rapid sensing and visualization of complex shapes.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Validated set of algorithms for real-time data normalization of multiple channels and data fusion processing.
Technical Issues	Fusion of data from multiple high-resolution sonar systems or from multiple looks with varying aspect angles using the same sonar and displaying the information from either for rapid visualization of complex shapes with very high resolution.
Major Commercial Applications	Submersible small object location and obstacle avoidance.
Affordability	None identified.

RATIONALE

High-resolution active sonar is a valuable asset for submarines and submersibles to use for safely navigating in uncharted areas; for operating near the sea floor and under ice; and for detecting, locating, and identifying objects. However, reverberation and low-resolution returns that are cluttered and confusing hamper the use of active sonar in these environments. Data-fusion processing of multiple-source data in conjunction with an intuitive visualization display has the potential for rapidly sensing and resolving complex shapes.

The added capability of high resolution navigation for submarines and submersibles will provide a significant contribution for operating in littorals and other cluttered undersea areas, which supports the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

No other country is known to be developing this capability. The capability is driven by military applications.

DATA SHEET III-17.2. ACTIVE SONAR FOR UNDERWATER WEAPONS

Developing Critical Technology Parameter	For underwater weapons, active sonar having multiple preformed beams with transmit frequency greater than 15 kHz, able to withstand depths greater than 500 m, to transmit sound pressure levels greater than 220 dB (reference to 1 μPa at 1 m), to detect, classify, identify, and resolve targets at ranges greater than 1,000 m, with angular accuracy better than 5 deg and Doppler accuracy better than 2 knots in clutter.
Critical Materials	Piezoelectric composites and magnetostrictive terfernol D.
Unique Test, Production, Inspection Equipment	Fixed and portable underwater tracking ranges for testing computer-aided processes and obtaining the data base for developing computer-aided processing algorithms.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real-time target resolution, identification, and tracking.
Technical Issues	Identifying and selecting the weighting of clues that discriminates between USW targets and nontargets and selecting and implementing the decision criteria that combined provide a probability of detection and classification greater than 95 percent with a false-alarm rate of less than 5 percent for small, quiet, electric-propulsion submarines in harsh, shallow water environments. This unique military capability is constrained by the difficulty of obtaining realistic and representative data at sea and perfecting the series of processes. Additional issues are self-noise and target resolution versus torpedo size.
Major Commercial Applications	None identified.
Affordability	The cost for obtaining the necessary environmental acoustic database and the cost of weapon proofing are major factors for expendable weapons.

RATIONALE

Active sonar is a critical ingredient for the final homing of an acoustic homing torpedo. An acoustic homing torpedo generally acquires a target from information provided by the launching platform or its self-contained passive sonar and then closes quietly until it reacquires with active sonar. Because the target is alerted at that time, the torpedo increases speed for the final homing sequence, and the passive sonar goes blind. Active sonar in the small diameter of a torpedo traveling at speeds of over 40 knots is limited by transmit source level, target resolution, angular and Doppler accuracy, and high self-noise. The combined improvements (see the table) have the potential to overcome these limits, giving torpedoes the capability of acquiring the target at extended ranges and at great depths and rapidly homing by tracking the target at high speeds and at fast turning rates to prevent the target from escaping.

The combined underwater weapon advanced technologies of computer-aided detection, tracking, classification, and identification of undersea targets in harsh acoustic environments will aid ASW forces executing the Joint Vision 2010 operational concepts of precision engagement, dominant maneuver, and full-dimensional protection

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●●	Germany	●●●	Italy	●●	Japan	●●
Russia	●●●	Sweden	●●	UK	●●●	United States	●●●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The United States leads in underwater weapons active sonar development. France, Germany, Russia, and the UK follow. Italy, Japan, and Sweden come next. All of these have reasonably complete capability in acoustic sensors and weapons, largely sustained by competent laboratories and industry. The capability is entirely driven by military applications.

DATA SHEET III-17.2. ACTIVE SONAR FOR MINE COUNTERMEASURES

Developing Critical Technology Parameter	For mine-hunting sonars, an adaptive beam-forming process that steers nulls toward the bottom and surface interfaces to reduce the reverberation interference that blanks the mine targets in the water column.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real time, dynamic tracking of the sea surface and bottom interfaces with the water column.
Technical Issues	To identify, select, and track the sea surface and bottom interfaces with the water column in order to steer nulls of greater than 20 dB at the interfaces that are causing reverberation interference. This interference blanks the sonar and suppresses mine targets in the water column, especially for mines that are tethered near the bottom.
Major Commercial Applications	Detecting fish near the sea bottom.
Affordability	None identified.

RATIONALE

The importance of active sonar for mine hunting and neutralization has continued to increase with the world-wide emphasis on littoral warfare and the proliferation of relatively inexpensive sea mines. Sea mines have the potential for sinking or severely damaging high-value units, as well as for delaying or removing an option for naval action because of the mine threat to navy vessels and personnel. Active sonar is the most commonly used sensor for detecting, identifying, and accurately locating sea mines. Active sonar has the largest area coverage for rapid clearing of a minefield; however, active sonar is hampered by reverberation interference and the resulting low signal strength received, complex and confusing returns from mine-like false targets on the sea bottom, low probability of correct decisions, high false-alarm rate, and operator overload. The capability to dynamically adjust a null of greater than 20 dB in order to reduce the blinding effect of reverberation has the potential for significantly increasing the probability of detection and classification of mines and mine-like false targets.

The added capability of suppressing bottom reverberation for mine-hunting sonars will provide a significant contribution to USW forces, which supports the Joint Vision 2010 operational concepts of dominant maneuver and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Germany	●	Japan	●	Russia	●
UK	●●	United States	●●●				

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The United States leads in developing advanced mine-hunting sonars that have null steering capability. France, Germany, the UK, and possibly Japan and Russia are exploring this capability. No other country is known to be involved. This capability is driven by military applications.

DATA SHEET III-17.2. ACTIVE SONAR FOR ANTI-TORPEDO TORPEDOES

Developing Critical Technology Parameter	To detect, resolve, and track incoming torpedoes at ranges greater than 100 m and with an accuracy of within 5 m.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real-time target detection, resolution, and tracking.
Technical Issues	An active sonar incorporated in an anti-torpedo torpedo to detect, resolve, and track incoming torpedoes at speeds greater than 50 knots, at ranges greater than 100 m, and with an accuracy of within 5 m.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

More and more homing torpedoes are being developed and built that have wake homing and other nonacoustic sensors that cannot be readily countermeasured. The nonacoustic homing torpedoes are a serious threat to high-value naval surface units such as aircraft carriers and troop transport ships. Anti-torpedo torpedoes are being developed to hard kill the threat torpedo as opposed to the soft kill (countermeasures) often used against acoustic homing torpedoes. Hard kill is difficult because the target must be resolved, acquired, and tracked to within 5 m for an effective kill. Active sonar is a critical ingredient for the final homing of an acoustic homing anti-torpedo torpedo. Acoustic homing anti-torpedo torpedoes generally acquire a target from information provided by the launching platform. Active sonars in the small diameter of a torpedo traveling at speeds of over 40 knots are limited by target resolution, angular and Doppler accuracy, and high self-noise. Acoustic homing anti-torpedo torpedoes using high-resolution active sonar have the potential for overcoming these limits and acquiring a fast-moving target torpedo at ranges over 100 m with an accuracy of within 5 m.

The capability of destroying incoming torpedoes regardless of homing features will provide a vital contribution to surface warfare forces, which supports the Joint Vision 2010 operational concept of full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Germany	●	Russia	●●	UK	●●
United States	●●●						

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States leads in active sonar development for anti-torpedo torpedoes. The UK, France, Germany, Japan, and Russia have commenced or are considering implementing such developments. All have reasonably complete capability in acoustic sensors and weapons, largely sustained by competent laboratories and industry. The capability is entirely driven by military applications.

SECTION 17.3—ACOUSTIC SENSORS, MARINE, PASSIVE SONAR

Highlights

- Passive sonars are totally covert and are the sensor of choice in several operational scenarios.

- Major improvements in passive sonar systems are required to counter the worldwide submarine-quieting programs.

- Target transients, which are difficult to quiet, are to be exploited by employing unique processing and data management.

- Advanced processes are being developed to extend operational target ranges, thereby expanding the search area coverage.

- Automated target detection, classification, identification, and tracking are being developed for evasive submarine targets.

- Receiving array gain is being increased and self-noise reduced for both hull-borne and towed arrays.

- Advanced processes are being developed for reducing the time required for ranging, tracking, and developing a fire-control solution.

- It is envisioned that evolutionary improvements in passive sonars will continue, but at an accelerated pace.

OVERVIEW

This subsection covers the technology for the development and production of passive sonar systems that are used militarily for the covert location of underwater objects that radiate energy. Passive sonars are used primarily for antisubmarine and anti-surface-ship warfare. Functions performed are detection, classification, identification, location, and tracking of acoustically radiating targets. The radiating energy is created by target vehicle propulsion and maneuvering, flow noise, transmitted acoustic signals, weapons launch, mine and torpedo actuators, and performance of housekeeping functions. Passive sonars are incorporated in submarines, surface ships, mines, torpedoes, and bottom-mounted or deployed sites. They are also incorporated in aircraft by using sonobuoy sensors. Passive sensor arrays are both mounted on the hulls of and towed from submarines, surface ships, and torpedoes.

Passive sonar performance is dependent on the acoustic environment. The major interferences are own-ship noise, radiated noise from nearby friendly ships, noise from shipping at long ranges, and ambient background noise. The ASW passive sonar frequency band has been extended to the lower few hundred hertz as submarines have become quieter. Propagation paths are the same as for active sonar, except the path is only one way. Detection ranges of 30 to 60 km are possible with towed arrays, and hundreds of kilometers are possible with fixed or deployed sites operating against transiting submarine targets. The detection range is shorter for submarine targets operating in the quiet mode or in littoral areas. Underwater weapons passive sonars are designed to operate out to 20 km, while discriminating the target-radiated noise from the weapon self-noise, ambient background noise, and countermeasures.

There are few civilian uses for passive sonar except for academic research. The major concern is with "active" systems—marine seismic towed hydrophones arrays (streamers) and ocean bottom cable systems—that can be used in the passive mode for ASW. Passive sonars have been developed uniquely for naval use. All U.S. Navy passive sonars are U.S. developed and produced. Some advanced technologies are shared with close allies, but relatively few systems are exported.

Evolutionary, emerging technology developments are highlighted in the following data sheets. There are no known revolutionary, emerging technology developments underway.

RATIONALE

Most successful ASW is performed using a mix of active and passive sonar systems based on the operational scenario. Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode, for the initial contact in an engagement, and for intercepting transients from the opponent's platform and weapons. In those roles, towed hydrophone arrays are the most effective ASW sensor used to date. As fixed, bottom-mounted surveillance sites are phased out, more reliance is being placed on long-towed arrays and deployable arrays. Towed and deployed arrays have less detection range than the major bottom-mounted sites, but are readily transported to the operating area of interest. The fixed sites cannot be readily moved. Passive sonar effectiveness is being enhanced by sharing data among several platforms. The effectiveness will increase in the future when such data is shared more widely and faster using an operational network (network-centric warfare).

When the long-range passive systems are not available, the fleet is potentially very vulnerable to submarine attacks using long-range torpedoes and standoff weapons. Current passive sonars are limited, in that they are susceptible to noisemaker type countermeasures and loud ambient background noise and may require several minutes to develop a target track suitable for weapons launch. The major technology developments discussed in the following data sheets are expected to overcome these deficiencies.

WORLDWIDE TECHNOLOGY ASSESSMENT

Country	Intercept Receivers	Open-Ocean Deployed Passive Sonar	Sonobuoys	Underwater Weapons Passive Sensors	Passive Sonar Target Tracking	Passive Sonar Reception
Australia	●		●●	●●		●●
Canada	●		●●			●●●
China	●		●	●●		
France	●●●	●●	●●●	●●●	●●●	●●
Germany	●●		●●	●●	●●	●●
Italy	●					
Japan	●●		●●	●●●	●●	●●
Netherlands	●					
Russia	●●	●●	●●	●●	●●	●●
Sweden	●			●●		
UK	●●●	●●	●●●	●●●	●●●	●●
United States	●●●●	●●●●	●●●●	●●●●	●●●●	●●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

(Continued)

Figure 17.3-1. Acoustic Sensors, Marine, Passive Sonar Systems WTA Summary

Country	Passive Sonar Ranging	Passive Sonar Data Fusion	Passive Sonar Array Noise	Passive Sonar Adaptive Beamforming, Null Steering, and Sidelobe Reduction	Passive Sonar Hull-Mounted Receiving Arrays	ASW Volumetric Towed Arrays
Australia	●●					
Canada	●●					
China						
France	●●●	●			●●	●●
Germany	●●				●	●
Italy						
Japan	●●				●	
Netherlands						●
Russia	●●				●●	
Sweden					●	
UK	●●●	●			●●	●●
United States	●●●●	●●	●●	●●●●	●●●	●●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●
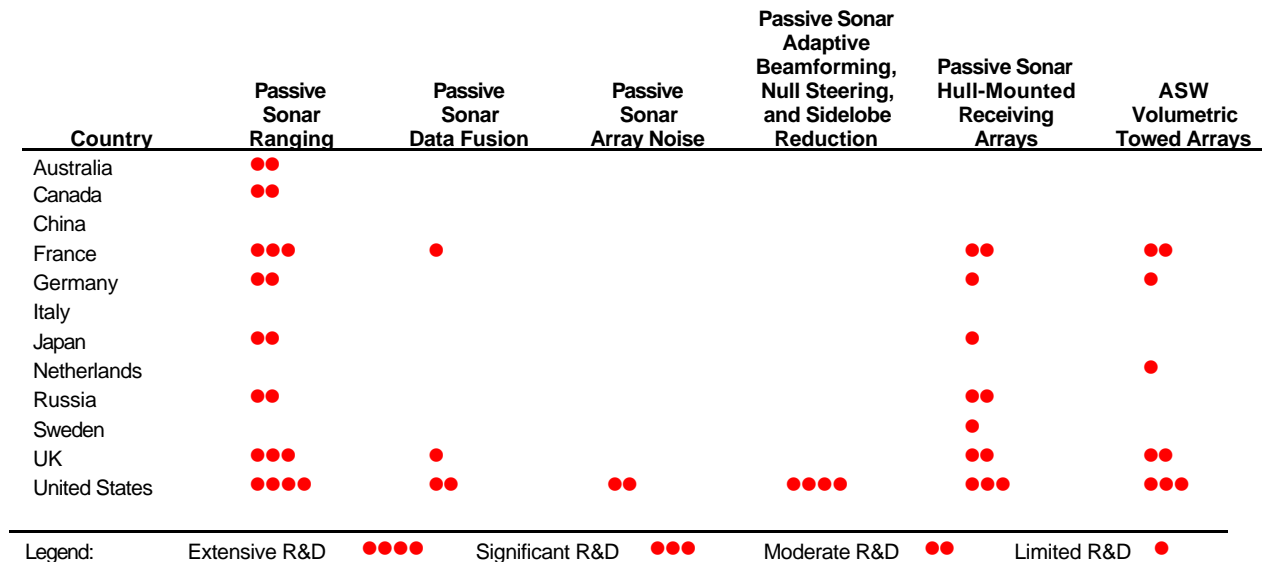
Figure 17.3-1. Acoustic Sensors, Marine, Passive Sonar Systems WTA Summary (Cont'd)

The United States has consistently maintained a comfortable lead in passive sonar systems technology over Russia and the major western sonar-producing countries. France and the UK clearly pace the remainder of the Western World and, though smaller in size, still lead Russia in many technology areas. Germany and Japan come next in quality of passive sonars, followed by Australia and Canada. A few other countries have capabilities in niche areas.

LIST OF TECHNOLOGY DATASHEETS
III-17.3. ACOUSTIC SENSORS, MARINE, PASSIVE SONAR

DATA SHEET III-17.3. INTERCEPT RECEIVERS

Developing Critical Technology Parameter	Interception of acoustic transients with 360-deg coverage for the full acoustic spectrum of 10 Hz through 300 kHz and having bearing determination with less than 5-deg error for multiple and overlapping targets.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) selecting the clues that classify and identify transients; (2) implementing the identification process; and (3) developing and implementing the decision criteria. These sets of algorithms are for the functions of classification, identification of transient signals, and determining the bearing of the transient source.
Technical Issues	The identification, selection, and weighting of clues for the classification and identification of intercept signals; for maintaining target bearing accuracy of less than 5 deg at frequencies greater than 30 kHz; and for achieving a false-alarm rate of less than 3 percent.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain a wide variety of realistic platform and weapon transient signals and target-like false-target signals is a limiting factor.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode, for the initial contact in an engagement, and for intercepting transients from the opponent's platform and weapons. Passive sonar is designed to detect continuous noise sources, often those that are repetitive in nature. Impulse-type noise or sounds of short duration and nonrepetitive nature are discriminated against. The unique role for intercept receivers is detecting, classifying, and identifying platform- and weapon-type transients that are suppressed by the basic passive receiver, but provide a wealth of information on opposing platform and weapon actions. The need is to provide 360-deg coverage, to identify multiple transient sources accurately, and to determine the bearing within 5 deg for all acoustic frequencies.

The added capability of full-coverage transient intercept will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●	Canada	●	China	●	France	●●●
Germany	●●	Italy	●	Japan	●●	Netherlands	●
Russia	●●	Sweden	●	UK	●●●	United States	●●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States has maintained a comfortable lead in intercept receiver technology over Russia and the major western sonar-producing countries. France and the UK clearly pace the remainder of the Western World and, though smaller in size, still lead Russia. Germany and Japan come next in quality of intercept receivers, followed by Australia, Canada, China, Italy, Netherlands, and Sweden.

DATA SHEET III-17.3. OPEN-OCEAN-DEPLOYED PASSIVE SONAR

Developing Critical Technology Parameter	The detection of multiple electric-propulsion submarines traveling at speeds of less than 6 knots at one convergence zone range (30 to 60 km) using a deployed array.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) compensating for an irregular array shape, (2) data rate reduction, (3) data fusion, and (4) developing and implementing the decision criteria.
Technical Issues	The method for deploying an expendable array containing hundreds of hydrophones and covering an operating area, powering the deployed electronics, data flow, fusion and management, data processing for the terminating receiver, and affordable cost.
Major Commercial Applications	None identified.
Affordability	The relatively low cost of the expendable array is critical for effective use.

RATIONALE

Passive sonar remains the sensor of choice for monitoring submarine movements through choke points, straits, or barrier situations. Experience has shown that tactical ASW is far more successful if and when general submarine movements are known. With the proliferation of quiet, electric-propulsion submarines throughout the world, the place of engagement will vary from conflict to conflict. Fixed surveillance sites are expensive and limited in use. A deployed, expendable array that has the potential to cover an ocean basin area for a minimum of 3 months provides the best solution. The deployed array is intended as a data source for a conventional passive receiver designed for detecting and locating continuous noise sources, often those that are repetitive in nature. Impulse-type noise or sounds of short duration and nonrepetitive nature are discriminated against. The deployed array, however, can also be used as a data source for detecting, classifying, and identifying platform- and weapon-type transients that are suppressed by the basic passive receiver but provide a wealth of information on opposing platform and weapon actions.

The added capability of advanced deployed arrays will aid ASW forces executing the Joint Vision 2010 operational concept of full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Russia	●●	UK	●●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States has maintained a lead in open-ocean deployed-array technology over Russia, France, and the UK. No other countries are known to have an active program.

DATA SHEET III-17.3. SONOBUOYS

Developing Critical Technology Parameter	The real-time detection, classification, identification, and determination of the bearing of submarine targets using inbuoy, automated processing, and beamforming, including receiving and processing signals from active adjunct transmissions and providing target location.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) selecting the clues that detect, classify, and identify potential targets, (2) implementing the identification process, and (3) developing and implementing the decision criteria. Also, validated sets of algorithms for determining the bearing of targets in the passive mode or the location of targets in the active mode.
Technical Issues	The identification, selection, and weighting of clues and the decision criteria and process for automated target detection, classification, and identification for both active and passive modes, for achieving target bearing with an error of less than 10 deg in the passive mode, for achieving target location with an error of less than 10 percent in the active mode, and for achieving a false-alarm rate of less than 10 percent for both.
Major Commercial Applications	None identified.
Affordability	The achieving of relatively low cost for expendable sonobuoys is critical to acceptance.

RATIONALE

Most successful ASW is performed using a mix of active and passive sonars based on the operational scenario. Airborne ASW using both active and passive sonobuoys is a vital part of the mix. The objective is to detect, classify, identify, and locate or determine the target bearing of quiet submarine targets at ranges greater than 1,000 m. With such accuracy, the monitoring aircraft can launch a homing torpedo, guide in ASW ships or submarines, or accurately call for a standoff weapon.

The added capability of advanced active/passive sonobuoys will aid ASW forces executing the Joint Vision 2010 operational concept of precision engagement and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	Canada	●●	China	●	France	●●●
Germany	●●	Japan	●●	Russia	●●	UK	●●●
United States	●●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States has maintained a comfortable lead in advanced sonobuoy technology over Russia and the major western sonar-producing countries. France and the UK pace the Western World and, though smaller in size, still lead Russia. Germany and Japan come next in quality of advanced sonobuoys followed by Australia, Canada, and China.

DATA SHEET III-17.3. UNDERWATER WEAPONS PASSIVE SENSORS

Developing Critical Technology Parameter	The real-time automated target detection, classification, and identification of the flow noise from quiet, electric-propulsion submarines maneuvering at less than 5 knots and at ranges out to 20 km to achieve the following: target track with an error of less than 20 percent and false-alarm rate of less than 10 percent while rejecting counter-measures, all from an autonomous underwater weapon traveling at over 30 knots.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Nose assembly and body machining.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) identifying, selecting, and weighting the clues that detect, classify, and identify potential targets, (2) implementing the automation process, (3) developing and implementing the decision criteria, and (4) tracking the target.
Technical Issues	The reduction of own weapon flow and self-noise; packaging within the small diameter, torpedo-shape-type body; target resolution and tracking when operating from a small-diameter, torpedo-shape-type body; and robustness against countermeasures.
Major Commercial Applications	None identified.
Affordability	The achieving of relatively low cost for expendable torpedoes is critical to acceptance.

RATIONALE

Most ASW acoustic homing mines and torpedoes initially seek their targets with passive sensors. The challenge is to detect and track slow, quiet submarines in an acoustically cluttered environment at ranges out to 20 km while the weapon is traveling at speeds up to 40 knots. The acoustically cluttered environment may contain jamming and decoying countermeasures. With the weapon operating in the passive mode and traveling at modest speeds, counterdetection at long ranges is minimized. The overall objective is to passively track and overtake the target to within 1,000-m range, at which point the target is reacquired by active sensors, and the weapon then homes in at high speed and with sufficient accuracy to destroy the target.

The combined underwater weapons advanced technologies of computer-aided detection, tracking, classification, and identification of undersea targets in harsh acoustical environments will aid ASW forces executing the Joint Vision 2010 operational concept of precision engagement.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	China	●●	France	●●●	Germany	●●
Japan	●●●	Russia	●●	Sweden	●●	UK	●●●
United States	●●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States has maintained a comfortable lead in advanced passive acoustic-homing technology over Russia and the major Western sonar-producing countries. France and the UK pace the remainder of the Western World and, though smaller in size, still lead Russia. Germany and Japan come next in quality of advanced passive homing, followed by Australia, China, Italy, and Sweden.

DATA SHEET III-17.3. PASSIVE SONAR TARGET TRACKING

Developing Critical Technology Parameter	Passive sonar capable of resolving and real-time tracking multiple submarine targets traveling at various speeds and at ranges out to 30 km.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that resolve and track multiple targets identified as submarines with an accuracy sufficient for a fire-control solution.
Technical Issues	Capability to resolve submarine targets in order to track multiple, maneuvering targets at ranges out to 30 km in a nonstationary noise field, with enough accuracy to derive a fire-control solution within 5 minutes after target identification.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Most successful ASW is performed using a mix of active and passive sonars based on the operational scenario. Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. In those roles, towed hydrophone arrays have increased the detection range of submarines tenfold. The challenge is to exploit this extended range to advantage and develop the capability to resolve and track multiple, maneuvering targets out to 30-km range in an acoustically cluttered environment. The tracking data is then applied directly to the fire-control solution.

The added capability of accurate, long-range tracking of multiple targets will aid ASW forces executing the Joint Vision 2010 operational concepts of precision engagement and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●●	Germany	●●	Japan	●●	Russia	●●
UK	●●●	United States	●●●●				

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The United States has maintained a lead in target tracking technology over France, Germany, Japan, Russia, and the UK. No other countries are known to have an advanced program.

DATA SHEET III-17.3. PASSIVE SONAR RECEPTION

Developing Critical Technology Parameter	Real-time, computer-aided detection, classification, identification, and tracking of quiet submarine targets at ranges out to 30 km with high probability of correct detections and low false-alarm rates.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) selecting the clues that detect, classify, and identify potential targets, (2) implementing the identification process, (3) developing and implementing the decision criteria, and (4) developing and implementing the normalization and thresholding of data received from multiple sources. Also, a validated set of algorithms for determining and implementing target track.
Technical Issues	The identification, selection, and weighting of clues and the decision criteria and process for computer-aided detection, classification, identification, and track of quiet, electric-propulsion submarine targets traveling at speed of less than 8 knots and at ranges out to 30 km, with a probability of detection greater than 90 percent and a false-alarm rate less than 10 percent, based on flow or propulsor-related noise or the processing of multiple tracks. Also, developing and implementing the process for normalization and thresholding of incoming signals from multiple sources.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Most successful ASW is performed using a mix of active and passive sonars based on the operational scenario. Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. Extensive quieting of electric propulsion submarines, however, has severely shortened the passive detection range. This reduction has being countered with the use of towed hydrophone arrays. The emphasis on detection and track of submarine targets based on flow and propulsor noise is a further hedge against submarine quieting because these noise components cannot be as easily reduced.

The added capability of computer-aided passive sonar decision capability will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	Canada	●●	France	●●	Germany	●●
Japan	●●	Russia	●●	UK	●●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States has maintained a comfortable lead in advanced, computer-aided processing technology over Russia and the major western sonar-producing countries. France and the UK pace the remainder of the Western World and still lead Russia. Germany and Japan come next in quality of advanced processing, followed by Australia and Canada.

DATA SHEET III-17.3. PASSIVE SONAR RANGING

Developing Critical Technology Parameter	Determining target range within 1 min after detection of quiet submarine targets at ranges out to 30 km.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Hull-mounted array installation and alignment.
Unique Software	Empirically validated set of algorithms for determining target range using irregular array shapes and for determining the location of array sensors and overall array shape.
Technical Issues	Determine target range with accuracy to ± 5 percent using wavefront curvature or triangularization techniques from an irregular array shape configured from hull-mounted and towed arrays; the ability to determine array sensors' location and overall array configuration to within a few centimeters. Additional issue is increased array quieting.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. Target range is an important ingredient for an accurate fire-control solution. Passive ranging using time motion analysis requires around 10 minutes with the target on a constant course and speed. Also, the extensive quieting of electric propulsion submarines in recent years has severely shortened the passive detection range. This reduction has being effectively countered with the use of towed arrays. However, for passive sonar to be effective against targets with standoff weapons, fire-control solutions are needed at maximum ranges. Currently, most fire-control solutions are performed using hull-mounted arrays with limited range. Passive sonar ranging using a mix of hull and towed arrays and employing wavefront curvature or triangularization-type techniques can be effective for ranging on targets at the maximum detection ranges and within 1-minute duration. The accuracy for this ranging technique is dependent on knowing the location of the array sensors and the overall array configuration to within a few centimeters. Array quieting is also necessary because the noisiest sensor determines the system self-noise that limits range.

The added capability of passive sonar rapid ranging will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	Canada	●●	France	●●●	Germany	●●
Japan	●●	Russia	●●	UK	●●●	United States	●●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States has maintained a comfortable lead in advanced, passive ranging technology over Russia and the major western sonar-producing countries. France and the UK pace the remainder of the Western World and still lead Russia. Germany and Japan come next in quality of advanced processing, followed by Australia and Canada.

DATA SHEET III-17.3. PASSIVE SONAR DATA FUSION

Developing Critical Technology Parameter	Real-time fusion of data received from two or more receiving arrays, including those from separate platforms, to increase overall target signal-to-noise ratio (SNR) and thereby increase detection ranges by 50 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for sorting data by specific target and accurately combining like data to increase target signal strength.
Technical Issues	Sorting and combining large and disparate data bases received from multiple arrays, with the fusion based on specific individual target characteristics such that target SNR is enhanced and detection range is increased by 50 percent.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. Extensive quieting of electric propulsion submarines in recent years, however, has severely shortened the passive detection range. This reduction is being countered with the use of towed arrays and can be further offset by using the data from a combination of arrays, including those on separate platforms, using network-centric warfare techniques. For the data fusion to be effective, the data must be accurately combined based on specific target characteristics.

The added capability of passive sonar data fusion will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●	UK	●	United States	●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States leads in advanced, passive data-fusion technology. France and the UK have or have had data-fusion programs. No other successful data-fusion developments are known.

DATA SHEET III-17.3. PASSIVE SONAR ARRAY NOISE

Developing Critical Technology Parameter	Electronic processes capable of real-time reduction of flow and acceleration self-noise by 6 dB or greater to increase target SNR and thereby increase detection ranges by 30 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for isolating target signals from noise.
Technical Issues	The isolation of target signals from flow- and acceleration-generated self-noise such that target strength is enhanced and target range increased by 30 percent.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. Extensive quieting of electric propulsion submarines in recent years, however, has severely shortened the passive detection range. This reduction is being countered with the use of towed arrays and data fusion from a combination of arrays. Further signal-to-noise improvements can be gained from reducing self-noise of mobile arrays by electronic processing.

The added capability of passive sonar-array noise reduction will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

No other advanced array self-noise cancellation programs are known.

DATA SHEET III-17.3. PASSIVE SONAR ADAPTIVE BEAMFORMING, NULL STEERING, AND SIDELOBE REDUCTION

Developing Critical Technology Parameter	Adaptive beamforming, null steering, and sidelobe-reduction processes capable of reducing interference from acoustic clutter and countermeasures by greater than 20 dB, thereby increasing detection ranges and nullifying countermeasures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for adjusting beams and steering nulls to enhance the target SNR.
Technical Issues	The isolation of target signals from acoustic noise and clutter normally received, using a combination of adaptive beamforming, null steering, and sidelobe-reduction techniques, such that interference is reduced by greater than 20 dB, thereby enhancing target SNR and increasing target-detection range. The same techniques to be used to nullify the effects of jammer countermeasures.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. Extensive quieting of electric propulsion submarines in recent years, however, has severely shortened the passive detection range. This reduction is being countered with the use of towed arrays and data fusion from a combination of arrays. Further signal-to-noise improvements can be gained from reducing by 20 dB the noise and clutter received from the acoustic environment by using a combination of adaptive beamforming, null steering, and sidelobe-reduction techniques. The 20-dB interference reduction can increase detection range by 20 to 30 percent. It will also nullify the major effects of jammer countermeasures.

The added capability from canceling or reducing distant interfering noise sources received by passive sonars will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States ●●●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

The United States leads in advanced interference-rejection technology. France and the UK have or had such programs. No other successful interference rejection developments are known.

DATA SHEET III-17.3. PASSIVE SONAR HULL-MOUNTED RECEIVING ARRAYS

Developing Critical Technology Parameter	Passive sonar capable of platform speeds greater than 20 knots and depths greater than 300 m without being self-noise limited by using sensor matching, array shading, or pressure-tolerant processing with greater than 10 dB self-noise reduction.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Array installation and alignment equipment.
Unique Software	Validated set of algorithms for pressure-tolerant processing.
Technical Issues	The isolation of hydrophone elements from the platform hull, determining and providing uniformity of hydrophone elements, and providing precise installation of the elements.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in an engagement. The extensive quieting of electric-propulsion submarines in recent years, however, has severely shortened the passive-detection range. Detection range is further reduced when the flow noise from platform speed and distortion of arrays from the pressure at depth creates the dominant background noise level. The advanced hull-mounted array installation processes can offset these reductions and allow maximum detection ranges at high speeds and great depths.

The added capability from reducing own ship interfering noise sources received by passive sonars will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Germany	●	Japan	●	Russia	●●
Sweden	●	UK	●●	United States	●●●		

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States leads in advanced hull-mounted array installation processes. France and the UK may have similar programs. Germany, Japan, Russia, and Sweden may have programs for hydrophone isolation. No other successful developments are known.

DATA SHEET III-17.3. ASW VOLUMETRIC TOWED ARRAYS

Developing Critical Technology Parameter	Volumetric towed arrays capable of increased target-detection ranges while maneuvering at tactical speeds by using multiple lines; strength members in hose wall; electronic cancellation of flow or acceleration noise; and vibration isolation and low-noise dynamic leveling with depression force greater than 100 pounds, both at tow speeds greater than 8 knots.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for electronic cancellation of flow- and acceleration-generated self-noise.
Technical Issues	Towing multiple arrays without entanglement during tactical maneuvering, incorporating durable strength members in hose wall with operational life of 2 years, dynamic leveling and depression of greater than 100 pounds at speeds greater than 8 knots for the multiple arrays with no increase in self-noise, and electronic cancellation of flow- and acceleration-generated self-noise of greater than 6 dB for the individual arrays.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Passive sonar remains the sensor of choice for antisubmarine and anti-surface-ship warfare in the surveillance or standoff mode and for the initial contact in a melee engagement. The extensive quieting of electric-propulsion submarines in recent years, however, has severely shortened the passive detection range. This reduction is being countered with the use of towed arrays. Further signal-to-noise improvements and extended detection ranges can be gained from towing several shorter arrays on the order of 50 m instead of one or two arrays that are over 500 m long. In addition, the shorter, multiple-array arrangement will allow tactical maneuvering and speeds.

The added capability from towing volumetric towed arrays will aid ASW forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Germany	●	Netherlands	●	UK	●●
United States	●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States leads in advanced, multiple-line, towed-array technology. France, Germany, the Netherlands, and the UK have small programs. No other successful multiple-line array developments are known.

SECTION 17.4—ACOUSTIC SENSORS, MARINE PLATFORM

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Highlights

- Sonar domes and windows are required to protect sonar transducer and hydrophone elements and are an integral part of the operational platform.

- Acoustic signals are distorted and absorbed by the sonar domes and windows and their supporting structures.

- Platform self-noise must be reduced to counter the quieter submarine targets.

- Domes and windows need to be better isolated from the platform to reduce platform self-noise.

- All noise reduction needs to be effective over the depth excursion of U.S. submarines.

- The amount of self-noise reduction that is needed will require active noise-cancellation systems.

- It is envisioned that evolutionary improvements in platform self-noise reduction will continue, but at an accelerated pace.

</div>

OVERVIEW

This subsection covers the technology for the development and production of the interface of acoustic systems with the marine platform. This encompasses all measures taken to reduce the self-noise of ships, submarines, torpedoes, and other sonar platforms. Platform acoustic technologies have a major impact on the sonar systems' capability because they reduce self-noise generated by on-ship machinery or water flow around the platform. Specifically of interest are domes; baffles; the quieting of machinery, including main propulsion, valves, gears, pumps, fans, balancing and mounting of same, measurement techniques, and instrumentation; hull coatings; and active and passive structural noise control. Some of these items are partially covered under signature reduction of radiated noise in Signature Control Technology, Section 18. Radiated noise and ship self-noise that affects sonars often come from the same source, but the process for reduction of these noises can be quite different. There are no known commercial uses for the large acoustic domes and windows that are considered militarily critical. All self-noise reduction for marine platforms has been driven by military application. The U.S. Navy developed most of the acoustic processes covered in this section. Evolutionary, emerging technology developments are highlighted in the following data sheets. There are no known revolutionary, emerging technology developments underway.

RATIONALE

For the foreseeable future, active and passive sonar systems are expected to remain the dominant sensors on submarines and surface ships for antisubmarine, anti-surface-ship, and mine warfare. The sonar hydrophones and transducers must be effectively coupled to the water without being subject to damage by marine growth, objects in the water, waterflow, or wave action on the platform. They also need to be isolated from own-ship-generated noise, turbulent flow noise, and propulsor-generated noise. As such, the hydrophones and transducers are acoustically isolated as much as possible from the ship and protected from the ocean by an acoustically transparent dome or window. Unfortunately, structural integrity, acoustic isolation, and acoustic transparency are not generally compatible. A group of special materials and isolation techniques has been developed to minimize the problem.

Country	Acoustic Devices and Materials	Active Noise Cancellation
France	●●	
Germany	●●	
Israel		●
Russia	●●	
UK	●●	●
United States	●●●	●●

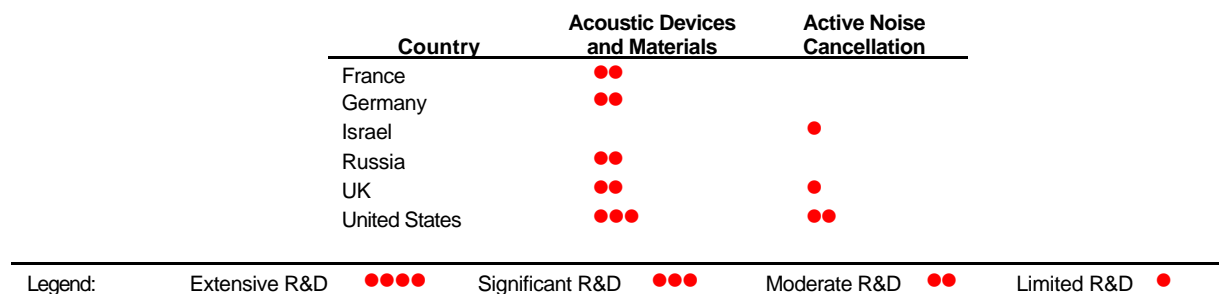Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

Figure 17.4-1. Acoustic Sensors, Marine Platform Systems WTA Summary

The United States has maintained a comfortable lead in nuclear-powered-submarine self-noise reduction (and the companion-radiated noise) over Russia, France, and the UK. The U.S. 688I class submarines were the quietest in the world. Russia then developed the AKULA Class, which appeared quieter. They are now developing a new attack class submarine, the SEVERODVINSK, which is to be even quieter. The latest U.S. attack class submarine, USS SEAWOLF, SSN-21, is slated to be the new, low-noise leader. The United States does not build diesel-electric submarines, but Australia, France, Germany, Japan, the Netherlands, Russia, Sweden, and the UK build quiet electric-propulsion submarines. Some of these submarines are reported to be quieter than many nuclear-powered ones. The United States has also led in surface-ship self-noise reduction. Most U.S. surface ships that were designed for ASW have the capability to effectively operate hull-mounted, passive sonars at medium, tactical operational speeds.

LIST OF TECHNOLOGY DATASHEETS
III-17.4. ACOUSTIC SENSORS, MARINE PLATFORM

DATA SHEET III-17.4. MARINE-PLATFORM ACOUSTIC DEVICES AND MATERIALS

Developing Critical Technology Parameter	Devices and materials that are capable of combined noise reduction of greater than 20 dB for frequencies less than 2 kHz or greater than 30 dB for frequencies from 2 to 5 kHz, with 90-percent effectiveness at speeds over 20 knots and over the depth excursion of U.S. submarines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Underwater anechoic test facility with pressure capability of 1,000 psi.
Unique Software	None identified.
Technical Issues	Capability of better isolating hydrophone and transducer elements from the self-noise and vibrations of the submarine hull by the use of advanced baffles, absorbers, conditioners, and decouplers that are effective over the depth excursion of U.S. submarines and maintaining the combined low insertion loss and reflectivity of the acoustic windows at speeds over 20 knots and over the depth excursion of U.S. submarines.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Active and passive sonar systems are expected to remain indefinitely the dominant sensors on submarines for antisubmarine and anti-surface-ship warfare. Great strides are being made in improving both active and passive sonar performances. The improvements are limited by the impact of the platform on the acoustic signals. The sonar hydrophones and transducers must be effectively coupled to the water without being damaged by marine growth, objects in the water, or by waterflow. They also need to be isolated from own-ship-generated noise, turbulent-flow noise, and propulsor-generated noise. As such, the hydrophones and transducers are acoustically isolated as much as possible from the ship and protected from the ocean by an acoustically transparent dome or window. Unfortunately, structural integrity, acoustic isolation, and acoustic transparency are not generally compatible. A group of special materials, techniques, and devices has been developed to minimize the problem. Reduction of 20 to 30 dB of platform self-noise is required to exploit the increased performance of future submarine sonars to counter the submarine quieting underway in the world's navies.

The added capability of advanced acoustics devices and materials will aid submarine warfare forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Germany	●●	Russia	●●	UK	●●
United States	●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States leads in advanced submarine hull-mounted-array installation processes. France, Germany, Russia, and the UK are recognized to have good capability in hull-mounted-array installations and have some advanced programs. No other significant developments are known.

DATA SHEET III-17.4. MARINE-PLATFORM ACTIVE NOISE CANCELLATION

Developing Critical Technology Parameter	Noise reduction of greater than 12 dB by active cancellation techniques.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	The reduction of self-noise by greater than 12 dB using active cancellation techniques, in which the noise is effectively separated from the signal, properly adjusted, and then subtracted from the total incoming data, all without reducing the desired signals.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Active and passive sonar systems are expected to remain indefinitely the dominant sensors on submarines for antisubmarine and anti-surface-ship warfare. Major improvements are being made in both active and passive sonar performances. The improvements are limited by the impact of the platform on the acoustic signals. The sonar hydrophones and transducers must be effectively coupled to the water without being damaged by marine growth, objects in the water, waterflow, or by wave action on the platform. They also need to be isolated from own-ship-generated noise, turbulent-flow noise, and propulsor-generated noise. As such, the hydrophones and transducers are acoustically isolated as much as possible from the ship and protected from the ocean by an acoustically transparent dome or window. Unfortunately, structural integrity, acoustic isolation, and acoustic transparency are not generally compatible. A group of special materials, techniques, and devices has been developed to minimize the problem. Noise reduction by passive techniques using baffles, absorbers, conditioners, and decouplers will not be sufficient to fully counter the quieter submarine targets. A further reduction of 12 dB or more using active techniques for canceling noise is also required.

The added capability of advanced active noise cancellation aid submarine warfare forces executing the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection.

WORLDWIDE TECHNOLOGY ASSESSMENT

Israel	●	UK	●	United States	●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States leads in advanced submarine hull-mounted-array self-noise cancellation. The UK has a small program. Israel has added this type capability to the flank array in its Gal-class submarines. No other significant developments are known.

SECTION 17.5—ELECTRO-OPTICAL SENSORS

Highlights

- This subsection concentrates on the technology for video sensors, image intensifiers, and focal plane arrays (FPAs) as generic technologies applicable to many military and civil applications.

- Uncooled FPAs are very significant because of lower cost and weight. Many opportunities for improvements exist.

- The midwave infrared (MWIR) and short wave infrared (SWIR) region is ripe for further exploitation—especially the 1,000- to 2,000-nm region.

- The active interest in space applications, both military and civil, have renewed interest in the long-wave IR (LWIR) region.

- Research and development (R&D) is underway to develop imaging solar blind detectors for air vehicle protection. Present systems are non-imaging.

OVERVIEW

The last 40 years of the 20th century brought amazing advances in the ability to create images of scenes at night. DoD, as well as its counterparts in other countries, largely funded the initial development work. The new technology has revolutionized warfare, as demonstrated in Vietnam and the Gulf War. A nation's military forces can now conduct operations at night with efficiency unknown before. A statement of Gen. H. Norman Schwarzkopf, Commander of the Coalition Forces during Desert Storm, best characterizes the new capability: "They couldn't see anything through their sights, and all of a sudden their tank exploded." (27 February 1991)

"Night vision" is normally considered to embrace two different technologies, image intensification and thermal imaging. Image intensification, which depends on reflected light from objects in the scene, developed earlier than thermal imaging—from an operational standpoint. Thermal imaging depends on blackbody radiation from objects in the scene.

Imaging with Reflected Photons

Image intensification, as it exists in the latest third-generation (vacuum) tubes used in aviation goggles, may be the end of the line for intensified systems development based on the vacuum intensifiers. Little future development is planned. Instead, development is focusing on two different areas of technology:

- Solid state intensifiers
- Exploitation of the 1,000- to 2,000-nm wavelength region.

Thermal Imaging

Thermal imaging systems for terrestrial applications deployed in the late 20th century operated primarily in two spectral wavelength regions: MWIR (3–5 μm) and LWIR (8–11 μm). These systems originally depended on cooled detector arrays for peak sensitivity, but in the 1990's detectors were developed that required minimal or no cooling. While the uncooled arrays do not achieve the high sensitivity of cooled detector arrays, there are numerous applications that are not possible with the cooled arrays. Without the requirement for cooling engines that consume power, lightweight, affordable systems such as personal viewers and vehicle driving aids are possible. A number of civil applications are appearing in 2000 because of the lower cost.

Space systems operate in several other spectral regions, mainly in the very long wavelength IR (VLWIR) region beyond 11 μm. Ultraviolet (UV) applications also exist. These are expensive, tend to use exotic detector materials, and see limited production.

Early thermal-imaging systems used scanned linear arrays, and much of the operational inventory has these systems. Upgrades to second-generation staring systems are underway, and most planned systems employ staring arrays that require no mechanical scanning.

The key developing technologies in thermal imaging include the following:

- Larger cooled staring arrays

- Multicolor and hyperspectral arrays

- Further improvements in uncooled arrays

- Exploitation of other spectral regions such as short wave IR (SWIR) and UV

- Improved affordability and producibility.

RATIONALE

Joint Vision 2010 includes the concept of "precision engagement," a "system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain the flexibility to reengage with precision when required" (p. 21).

Defense Technology Area Plans include the following:

Electro-optical Sensors

SE.06   Multifunction Electro-optical Sensors and Signal Processing
SE.59   Low-Light-Level Imaging Sensors

Electro-optical Technology

SE.33   Advanced Focal Plane Array Technology

SE.65   Long-Wavelength and Multispectral, Large-Area, Staring Focal Plane Arrays

The 1,000- to 2,000-nm wavelength region is important because new families of "eye-safe" laser illuminators and target designators[1] (see Subsection 11.1) are being deployed operationally. Active systems such as laser detection and ranging (LADAR)[2] can be exploited. The new lasers are limited to a narrow bandwidth in the 1,000- to 2,000-nm wavelength region and are invisible to conventional intensified system or human eyes. The ability to pulse the new lasers allows range-gated viewers that are capable of viewing through fog and smoke screens.

Larger cooled staring arrays are important because larger arrays provide more options for system designers. For example, they can trade field of view (FOV) for resolution.

Multicolor and *hyperspectral arrays* are important because they improve target discrimination, identification, and analyses.

Further improvements in uncooled arrays are important because higher sensitivity will widen the application spectrum and possibly replace some existing applications that use cooled arrays.

Exploitation of the MWIR spectral region is important because this is where missile and aircraft plumes mainly reside. One of the best atmospheric windows occurs around 4 μm.

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[1]   These are referred to as "eye safe lasers" because eye damage from exposure to the laser is limited outside the visible spectrum—approximately 400 to 1,500 nm.

[2]   LADAR may also be referred to as light detection and ranging (LIDAR). The term LIDAR is most usually applied to systems for atmospheric monitoring or effluent/chemical/biological detection. See Laurin Publishing, *PHOTONICS Dictionary,* 1999 edition.

Exploitation the UV spectral region is important because short-range detection of missiles in the solar blind region aids in the protection of low-flying vehicles such as helicopters.

Improved affordability and producibility is important because use of systems for individual warfighters depends on low cost and portability. High-performance thermal imaging systems are expensive and can benefit from flexible manufacturing lines, which can reduce cost by avoiding duplicative production facilities.

RANGE OF MILITARY APPLICATIONS

A rudimentary form of image intensification existed in the 1940's and 1950's. It was possible to view scenes at night using image converters and IR active illuminators. The early active systems of the 1940's and 1950's used IR blackbody sources, such as filtered searchlights. These still radiated considerable visible energy and were not covert. The filtered IR sources of the early active systems could not be pulsed, as can a laser. The development of cascaded electrostatically[3] focused image intensification and the S-20 photocathode in the 1960's eliminated the need for active illumination, creating a covert or passive viewer. The Starlight Scope, deployed first in Vietnam, was the forerunner of an extensive family of intensified night viewing equipment. The most recent manifestation of this technology is the night vision goggle used by both ground troops and aviators. The original passive intensifier required three cascaded devices, each with a gain of ~40 to achieve enough light gain to be passive. The goggle tube uses a micro-channel amplifier that provides the same gain as three older tubes. The latest third-generation tubes use a GaAs photocathode with higher gain and production yield than the S-20/25 multi-alkali photocathodes. New lasers are limited to a narrow bandwidth in the 1,000- to 2,000-nm wavelength region and are invisible to conventional intensified systems or human eyes.

Thermal imaging systems were deployed experimentally in Vietnam; the best known equipment was the early forward-looking infrared radar (FLIR) equipment deployed on the C–47 and C–130 Gunships. Thermal imaging systems are now (in the late 1990's) widely deployed operationally. These systems range from large, shipboard IR search and track (IRST) systems down to miniature, handheld thermal viewers and include missile night sights and seekers, vehicle driving aids, and airborne FLIR.

TECHNOLOGY ASSESSMENT

The rate of technology change in thermal imaging is expected to be more rapid than the technology based on reflected photons. Thermal imaging, based on large second-generation staring arrays, provides many new design opportunities not available with mechanically scanned linear arrays. For example, system designers no longer must be concerned about a shortage of photons. On the other hand, large numbers of pixels also require larger displays to benefit from the larger FOV possible. This is a problem in vehicles that frequently have no room for larger displays. A new range of man-machine interface issues arises.

Significant progress has also been made in uncooled arrays. These are usually based on ferroelectric materials and microbolometers. Civil applications exist now (late 1999), as well as military applications. These are finding applications for missions that require lower performance than available from cooled arrays. For uncooled arrays to match the performance of cooled arrays, the Defense Advanced Research Projects Agency (DARPA) estimates that a ten-fold increase in sensitivity is needed. The agency is planning programs to achieve this.

The use of image intensifiers (or image converters) in the 1,000- to 2,000-nm region is somewhat speculative and requires considerable research, development, and technology verification. There is believed to be a larger amount of available ambient reflected photons in the 1,000- to 2,000-nm wavelength region due to night airglow compared to that in the visible wavelength spectrum. This needs verification testing.

Advanced concept technology demonstrations (ACTDs) are vehicles for transition. None are identified in S&T documents at this time (1Q2000) but will be added when established.

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[3] Electromagnetically focused intensifiers existed and were used by astronomers. They were far too large and power hungry for most military applications.
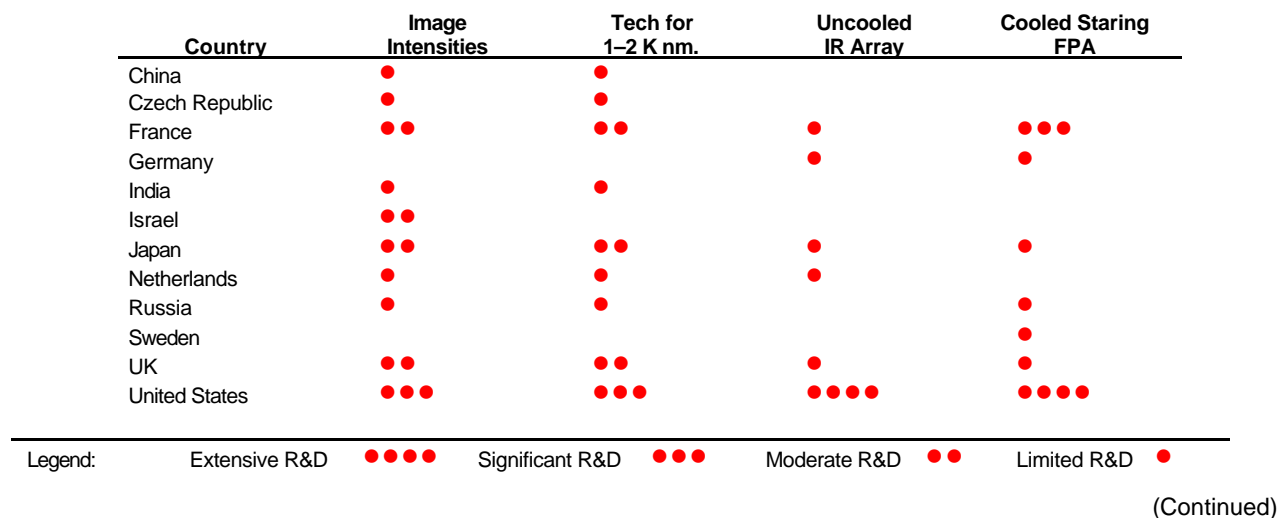
Country	Image Intensities	Tech for 1–2 K nm.	Uncooled IR Array	Cooled Staring FPA
China	●	●		
Czech Republic	●	●		
France	● ●	● ●	●	● ● ●
Germany			●	●
India	●	●		
Israel	● ●			
Japan	● ●	● ●	●	●
Netherlands		●	●	
Russia	●	●		●
Sweden				●
UK	● ●	● ●	●	●
United States	● ● ●	● ● ●	● ● ● ●	● ● ● ●

Legend: Extensive R&D ● ● ● ● Significant R&D ● ● ● Moderate R&D ● ● Limited R&D ●

(Continued)

Figure 17.5-1. Electro-Optical Sensors Systems WTA Summary

Country	Long and Dual Wave IR	Solar Blind Sensor	Single Pixel 3-Color
China			
Czech Republic			
France	● ● ●	● ●	● ● ●
Germany	●	●	●
India			
Japan	●	● ●	●
Netherlands			
Russia	●		
Sweden			
UK	●	● ●	
United States	● ● ● ●	● ● ●	●

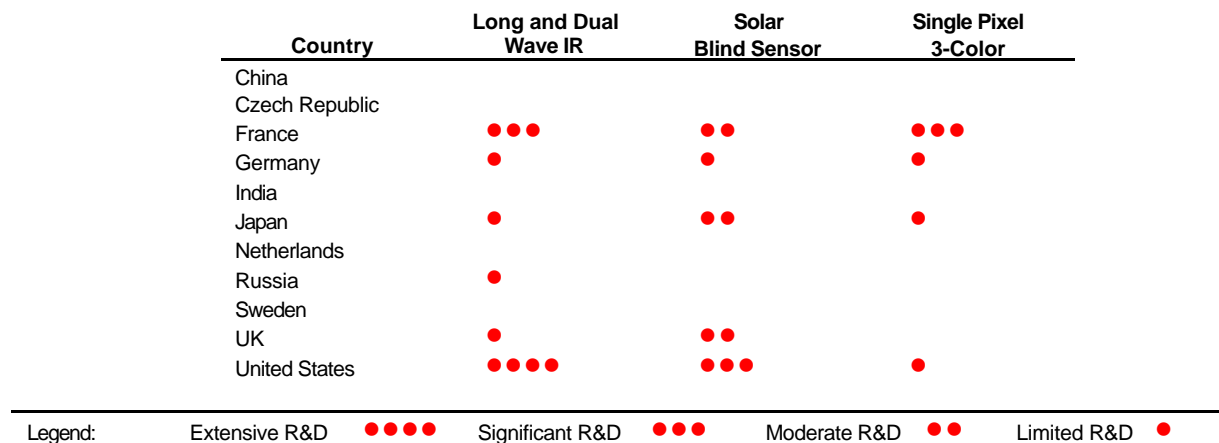Legend: Extensive R&D ● ● ● ● Significant R&D ● ● ● Moderate R&D ● ● Limited R&D ●

Figure 17.5-1. Electro-Optical Sensors Systems WTA Summary (Continued)

The United States, France, Germany, UK, Japan, Netherlands, and Russia are the current world leaders in EO technology. Several other countries have some capability—mainly in one or two types of EO sensors. China and India have a production capability for current image intensifiers derived initially from the import of technical data and know-how. China is advertising the sale of 8–14 μm handheld thermal imagers. The specification sheet lists "Uncooled Sprite detectors." The SPRITE detector is an invention of the UK government, uses HgCdTe material, and employs time delay and integration (TDI) within the SPRITE chip. It is the basis for UK military IR systems. Because HgCdTe does not work at this wavelength uncooled, it seems likely that this is not the UK product or that the specifications are incorrect. The Czech Republic has a long history with image converters and image intensifiers and was a core resource in the FSU. The United States, followed closely by France, is the world leader in cooled staring IR FPA technology; the United States is the leader in uncooled IR FPAs. Leading technology firms include Raytheon Infrared Center of Excellence, DRS, Litton Electro-Optical Systems, Sofradir (France), ORION RD&P Centre (Moscow), AIM (Germany), Old Delft & Phillips (Netherlands).

BACKGROUND:

Technology Centers of Excellence:

- **United States**

Raytheon Infrared Center of Excellence	DRS
75 Coromar Drive	13532 N Central Expy.
Goleta, CA 93117	Mail Stop 37
Phone: (805) 968-3511	Dallas, TX 75243
FAX: (805) 562-7373	Phone: (972) 344-4004
	http://www.amber-infrared.com

The Raytheon Infrared Center of Excellence and DRS resulted from the purchase of Hughes Electronics and the Texas Instruments Night Thermal Imaging Group, respectively, in 1996 by Raytheon. These are now the major facilities engaged in U.S. military thermal imaging research, development, and production. The major Hughes facility was the Santa Barbara Research Center, a world-class detector facility. The major TI facility was the Dallas-based producer of the U.S. military modular FLIR systems.

Litton Electro-Optical Systems
Infrared Products
1215 S 52nd St.
Tempe, AZ 85281
http://www.littoneos.com

Litton is a manufacturer of infrared detectors and focal plane arrays for IR imaging/detection applications and is active in SWIR and MWIR technology based in lead salt (PbSe, PbS) and indium antimonide (InSb) materials.

- **France**

Sofradir
43-47 rue Camille Pelletan
F-92290 Chatenay-Malabry
France
Phone: 33 1 41 13 45 30
FAX: 33 1 46 61 48 n84
Jpc@alpes-net.fr

Sofradir is the closest competitor for U.S. staring focal plane array manufacturers.

- **Russia**

ORION RD&P Centre
Plekhanov St. 2/46
Moscow 111123
Russia
Phone: 7 095 1761639
FAX: 7 095 1767221
Chap@orion.extech.msk.su

- **Germany**

AIM
Heilbronn, Germany

- **Netherlands**

Phillips
Old Delft, Netherlands

These Russian, German, and Dutch companies are also active in IR technologies.

LIST OF TECHNOLOGY DATA SHEETS
III-17.5. ELECTRO-OPTICAL SENSORS

DATA SHEET III-17.5. SOLID-STATE IMAGE-INTENSIFIER TECHNOLOGY

Developing Critical Technology Parameter	1. Low-light level (LLL). 2. 980 × 1,280 pixels with 10 μm pixels, wavelength range: 1,000–2,500 nm. 3. High-temperature operation using thermoelectric (TE) cooling.
Critical Materials	Mercury cadmium telluride (HgCdTe) and indium gallium arsenide (InGaAs).
Unique Test, Production, Inspection Equipment	Modulation transfer function (MTF) testers, night-vision scene simulators.
Unique Software	None identified.
Technical Issues	1. Adequate sensitivity with TE cooling. 2. High-speed, low-noise readout integrated circuit (ROIC) at low-light levels. 3. Low (2.5 W) power consumption. This technology is not constrained by a scarcity of professional, scientific, or technical personnel or skilled labor. Use of commercial technology is not applicable because the requirements here are much greater.
Major Commercial Applications	The same commercial applications as now exist for vacuum intensifiers (e.g., police and industrial surveillance, rescue missions, and sporting activities) can be expected. The commercial applications are not the drivers of this technology.
Affordability	Must be low cost because the sensors will be used at the "soldier level."

RATIONALE

Current image-intensification night-vision devices operate mainly in the visible spectrum and extend into the near infrared (NIR) by a very small amount. This response is referred to as "photopic" response. They are not operationally sensitive in the SWIR. Imaging devices that have significant sensitivity in the NIR and SWIR regions have important new capabilities that will extend the capability of photopic devices. They benefit from higher airglow irradiance. They have better camouflage penetration, and can see through glass and buildings.

WORLDWIDE TECHNOLOGY ASSESSMENT

China	●	Czech Republic	●	France	● ●	India	●
Japan	● ●	Netherlands	●	Russia	●	UK	● ●
United States	● ● ●						

Legend: Extensive R&D ● ● ● ●   Significant R&D ● ● ●   Moderate R&D ● ●   Limited R&D ●

This technology requires solid-state sensor expertise beyond that necessary for vacuum-type intensifiers and pickup tubes. The UK, Netherlands, Germany, Japan, Russia, and France, as well as the United States, have been active in R&D for night vision systems using pickup tubes and image intensifiers, including both civil and military systems. India, the Czech Republic, and China have the capability to produce past and some present generations of these devices. France, UK, Japan, and Germany are the most likely nations able to conduct R&D to meet the requirements described above.

DATA SHEET III-17.5. TECHNOLOGY FOR THE 1,000- TO 2,000-nm WAVELENGTH REGION

Developing Critical Technology Parameter	1. Solid-state imaging sensors capable of LLL sensitivity; 2. Optimize sensitivity at the wavelength of "eye safe" laser illuminators; and 3. 480 × 640 pixels
Critical Materials	III-V and II-VI semiconductor materials to be identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	1. Quantum efficiency for passive operation. 2. Tailoring the spectral response to available laser wavelengths for active, gated operation. This technology is not constrained by a scarcity of professional, scientific, or technical personnel or skilled labor. Use of commercial technology is not applicable because the requirements here are much greater.
Major Commercial Applications	None identified.
Affordability	Unknown.

RATIONALE

The 1,000- to 2,000-nm wavelength region is important because new families of "eye-safe" laser illuminators and target designators (see subsection 11.1) are being deployed operationally. Also, because of night airglow, there is believed to be a greater number of available ambient reflected photons in this region than in the visible wavelength spectrum. Active systems such as LADAR can be exploited. The new lasers are limited to a narrow bandwidth in the 1,000- to 2,000-nm wavelength region and are invisible to conventional intensified system or human eyes. The ability to pulse the new lasers allows range-gated viewers that are capable of viewing through fog and smoke screens.

WORLDWIDE TECHNOLOGY ASSESSMENT

China	●	Czech Republic	●	France	● ●	India	●
Japan	● ●	Netherlands	●	Russia	●	UK	● ●
United States	● ● ●						

Legend: Extensive R&D ● ● ● ●   Significant R&D ● ● ●   Moderate R&D ● ●   Limited R&D ●

This technology requires solid-state sensor expertise beyond that necessary for vacuum type intensifiers and pickup tubes. The UK, Netherlands, Germany, Japan, Russia, and France, as well as the United States, have been active in R&D for night vision systems using pickup tubes and image intensifiers. This includes both civil and military systems. France, UK, Japan, and Germany are the most likely nations able to conduct R&D to meet the requirements described above.

DATA SHEET III-17.5. UNCOOLED IR ARRAY TECHNOLOGY

Developing Critical Technology Parameter	High performance: sensitivity = 0.01 °C; resolution = 1 mil pixels, 1,000 × 1,000 pixels. Micro sensor: 160 × 120 pixels, 2 mil × 2 mil pixel size, no cooling, expendable, 1 oz., 10 mW with power management.
Critical Materials	Microbolometer and thin-film ferroelectric materials.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	1. Reduce pixel size. 2. Improve thermal isolation. 3. Increase sensitivity of microbolometers and ferroelectric devices. This technology is not constrained by a scarcity of professional, scientific, or technical personnel or skilled labor.
Major Commercial Applications	Vehicle driving aid, perimeter surveillance.
Affordability	Needs to be low cost because it will be used at the "individual soldier" level.

RATIONALE

Objectives of this technology:

- Smaller pixels and increased sensitivity;

- Larger formats;

- No mechanical chopper (as in pyroelectric detectors);

- No temperature stabilization;

- Lower power requirements;

- Higher frame rates; and

- Use of low-cost optics (see Section 11).

Payoffs:

- Lower cost;

- Longer autonomous life;

- Lighter weight;

- Smaller volume; and

- High performance (comparable to cooled arrays).

Advanced Focal Plane Array Technology (DTO SE.33) includes both cooled and uncooled arrays. The cooled technology focuses on dual-band and multispectral sensing for detecting dim and camouflaged targets in background clutter. The uncooled technology development aims for improved sensitivity and resolution while maintaining low cost, weight, and power consumption. The integration of IR and LLL FPA imaging in a single package will improve night-time rifle sight effectiveness and allow the development of low-cost missile seekers.

Military applications include UGS, remotely piloted vehicles (RPVs), smart munitions, hand-held and helmet-mounted systems, vehicle driver's viewer (also civil application), perimeter surveillance, and rifle sight.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●	Germany	●	Japan	●	Netherlands	●
UK	●	United States	●●●●				

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

At the present time (November 1999) the United States has a unique capability in the area of uncooled FPAs. Extensive R&D has been conducted for a number of years, and many applications, both military and civil, already are being implemented or planned. The applications are widespread, and significant improvements are possible. It is almost a certainty that some or all of the countries in the chart above are or soon will be engaged in significant R&D. Opportunities for cooperative R&D should exist.

DATA SHEET III-17.5. COOLED STARING FOCAL PLANE ARRAY TECHNOLOGY

Developing Critical Technology Parameter	Mega pixel arrays (from 1,024 × 1,024 to >2,048 × 2,048); higher operating temperature using thermoelectric (TE) or mechanical cooling (120–180 K) cooling; smaller pixels, 18 × 18 mm multi-color.
Critical Materials	HgCdTe
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	1. Achieving adequate manufacturing control for rapid turnaround and affordability. 2. Developing layered HgCdTe detector using molecular beam epitaxy (MBE) or metal oxide chemical vapor deposition (MOCVD) for dual-band sensors. 3. High-density silicon ROICs for on-chip and multi-spectral processing. 4. Alternate materials for selected spectral bands and higher operating temperatures. This technology is not constrained by a scarcity of professional, scientific, or technical personnel or skilled labor. Use of commercial technology is not applicable because the requirements here are much greater.
Major Commercial Applications	The technology described will result in extremely high performance and civil applications are not yet obvious. Civil applications are not drivers.
Affordability	Not an issue.

RATIONALE

Further improvements and new developments in cooled IR FPAs have significant payoffs for military applications:

- Improved target detection and discrimination;

- Longer range target identification;

- Counter-countermeasure (CCM) capability;

- Multi-operation modes;

- Reduced volume and lighter weight; and

- Lower system life-cycle cost.

Advanced Focal Plane Array Technology (DTO SE.33) includes both cooled and uncooled arrays. The cooled technology focuses on dual-band and multispectral sensing for detecting dim and camouflaged targets in background clutter. The uncooled technology development aims for improved sensitivity and resolution while maintaining low cost, weight, and power consumption. The integration of IR and LLL FPA imaging in a single package will improve night-time rifle sight effectiveness and allow the development of low-cost missile seekers.

Military applications of this technology are to detect low/obscured observables, future scout and combat vehicles, aviation, IR threat warning, and unmanned aerial vehicles (UAVs).

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●●	Germany	●●	Japan	●	Russia	●
Sweden	●	UK	●●	United States	●●●●		

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

The United States, followed closely by France, is the world leader in cooled staring IR FPA technology; the United States is the leader in uncooled IR FPAs.

Technology Centers of Excellence:

- **United States**

  Raytheon Infrared Center of Excellence
  75 Coromar Drive
  Goleta, CA 93117

  Litton Electro-Optical Systems
  Infrared Products
  1215 S 52nd St.
  Tempe, AZ 85281
  http://www.littoneos.com

  DRS
  13532 N Central Expy.
  Mail Stop 37
  Dallas, TX 75243
  http://www.amber-infrared.com

- **France**

  43–47 rue Camille Pelletan
  F–92290 Chatenay-Malabry
  France

- **Germany**

  AMI
  Heilbronn, Germany

- **Russia**

  ORION RD&P Centre
  Plekhanov St. 2/46
  Moscow 111123
  Russia

- **China**

  Guangzhou Sat Infrared Technology Co., Ltd.
  Beijing, China

It is unlikely that Guangzhou is developing staring IR FPAs. The company appears to be a "box" manufacturer.

DATA SHEET III-17.5. LONG- AND DUAL-WAVELENGTH IR FPA TECHNOLOGY

Developing Critical Technology Parameter	• 1,024 × 1,024 LWIR FPAs and 128 × 128 LWIR hardened for space. • Cutoff wavelength in the 14- to 25-µm range for space surveillance. • MWIR FPAs for threat warning.
Critical Materials	HgCdTe, silicon (Si)/HgCdTe, gallium indium antimony/indium arsenide (GaInSb/InAs) superlattice and gallium arsenide/aluminum gallium arsenide (GaAs/AlGaAs) quantum well materials.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Develop MBE technology to grow two to three layers of HgCdTe of different compositions monolithically, fuse data from different bands, condense smart readout circuitry into a 25-µm cell for ground applications and a 60-µm cell for space, discriminate distant cold targets against a cold background space, develop techniques for large-die ROIC.
Major Commercial Applications	The technology described will result in extremely high performance, and civil applications, other than Astronomy, are not yet obvious.
Affordability	Producibility of low-cost detectors.

RATIONALE

The technology described is intended to

- Provide improvements in the location and classification of missile launches;
- Provide improvements in location and classification of military forces and points of origin of bullets and munitions;
- Provide improvements in extracting targets from clutter; and
- Detect cooled midcourse targets from low-Earth orbit.

An example of an LWIR application is the discrimination of distant cold targets against a cold background space. In the MWIR an objective is two-color detection of approaching missile threats.

Producibility of low-cost detectors is an affordability issue. One approach is flexible manufacturing where many detector types are fabricated on the same line.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●●	Germany	●	Japan	●	Russia	●
UK	●	United States	●●●●				

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

In the United States major industrial contributors are Raytheon SBRC, DRS, Rockwell, and Lockheed Martin. Leaders in France are Sofradir and Liris, and in Germany, AIM in Heilbronn.

DATA SHEET III-17.5. SOLAR BLIND ULTRAVIOLET SENSOR TECHNOLOGY

Developing Critical Technology Parameter	Solar blind detector with a noise-equivalent power (NEP) of 10^{-14}.
Critical Materials	Gallium aluminum indium nitride (GaAlN) with a low ($<10^7$ cm^{-2}) defect density substrate material.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	• Fabrication of GaN-AlN based materials to achieve performance greater than that of photomultiplier tubes. • Fabrication/mating of readout circuitry for moderate size arrays.
Major Commercial Applications	None identified.
Affordability	Not an issue.

RATIONALE

An objective of this technology is the development of III-V nitride materials and detector technology to demonstrate an imaging ultraviolet FPA for threat warning applications. Current operational systems use vacuum, solar-blind photomultiplier tubes (PMTs) and are nonimaging.

Military applications are

- Aircraft and vehicle missile protection to provide high spatial/angulresolution; and

- Missile hardbody detection for space.

This is a unique enabling technology. Current PMT technology does not permit imaging.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	●●	Germany	●	Japan	●●	UK	●●
United States	●●●						

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

France, Germany, the UK, and Japan are the most likely countries to be engaged in solid-state UV FPA research; however, the only known current activity is in the United States.

DATA SHEET III-17.5. SINGLE-PIXEL THREE-COLOR LAYERED DETECTOR

Developing Critical Technology Parameter	Highest spatial resolution detector arrays which have the ability to sense red, green, and blue wavelengths by means of layered detectors on a single-pixel-element basis as required. The device, called the buried triple P-n junction (BTJ) structure can be fabricated using conventional bipolar or bipolar complementary metal oxide semiconductor (BICMOS) processes. Spatial resolution is tripled by this triad-stacking process. This technique eliminates the need for spectral filters. The amount of charge carriers generated depends on both the wavelength of the light and the depth at which it is absorbed. The BTJ exploits this by having three buried (layered) junctions, each producing a photocurrent. Sensitivity has been shown to be comparable or to exceed current visible-array detectors.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Temperature compensation sensitivity algorithms need to be developed. Mapping the device color to the visual range over a wide temperature range is needed.
Technical Issues	Drift and diffusion currents cause problems in detection. The BTJ structure has a "colorspace" that is not the same as that of the human eye. The photocurrent represented by the shorter wavelengths is particularly small, and the dark current increases disproportionately with temperature. Temperature compensation must be addressed. Noise sources will need to be minimized and readout compensation from the three layers will have to be addressed.
Major Commercial Applications	If the processes can be developed for mass production capability on current chips, the market is wide open. This technology will eventually replace current triad (side-by-side) color camera detector arrays.
Affordability	This technology should be more affordable than current technology at comparable resolution.

RATIONALE

The military will be able to achieve three times the spatial resolution of current detector arrays used in many surveillance and remote sensing devices. Battlefield surveillance will provide much higher resolution.

WORLDWIDE TECHNOLOGY ASSESSMENT

France	● ● ●	Japan	●	United States	●

Legend:	Extensive R&D	● ● ● ●	Significant R&D	● ● ●	Moderate R&D	● ●	Limited R&D	●

The French have developed the first prototype detectors using this technology. Mohamed Ben Chouikha and his colleagues at the University of Pierre and Marie Curie (Jussieu, France) have produced numerous publications on this technology, starting around 1997. There have been some attempts by U.S. researchers to duplicate the technology, but there are no publications by anyone else to date.

REFERENCES

Proceedings of SPIE, Vol. 3226 (1997).

"Tristimulus color sensitive photodetector in a BiCMOS technology," M. Ben Chouikha, G.N. Lu, M. Sedjil, G. Sou, *Université de Paris VI,* France [3226-19].

"Buried double p–n junction structure using a CMOS process for wavelength detection," G. Lu, M.B. Chouikha, M. Sedjil, G. Souy, G. Alquie, S. Rigo, *Université de Paris VI*—Pierre et Marie Curie, Paris, France [3226-21].

The XXVIth General Assembly of URS, August 13–21, 1999 on the Campus of the University of Toronto, Ontario, Canada. This Assembly brings together a majority of the leading researchers in a variety of electromagnetic and radio frequency disciplines.

Commission D: Electronics and Photonics; Chair: R. Sorrentino (Italy); Vice-Chair: A. Seeds (UK)

D6 – Optoelectronic Devices and Integration; M. Wu (USA) August 16, 14:00–18:00

"Modeling and Investigation VLSI Color Detectors Using Buried p–n Junctions," M. Sedjil, G.N. Lu, M.B. Chouikha, G. Alquie, *Université de Paris VI,* Paris, France.

DATA SHEET III-17.5 INFRARED ANTENNAS IN FPA FORMAT

Developing Critical Technology Parameter	• Within next 5 years, antenna-coupled, uncooled IR FPAs will provide high-speed, polarization-resolved, wavelength resolved IR imagery using uncooled FPA technology. • Goals are uncooled IR sensors of 10–100 NETD. These sensors will be in FPA format of nominal 512×512. These sensors will be tunable in wavelength response over the 3–5 and 8–12 µm bands, with 0.5-µm bandpass. Sensors will be tunable in polarization response for all linear polarization states as well as Left Circular and Right Circular. Tuning shall be in response to a dc voltage of 100 mV.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	• Production—direct-write electron-beam lithography. • Testing—custom apparatus currently under development for assessment of tuning functionality. • Inspection—usual IC inspection techniques.
Unique Software	None Identified.
Technical Issues	• Demonstration of initial feasibility with an array nominally equal to the uncooled infrared sensors currently in commercial production, at least 160×120 array with 0.100 K sensitivity. • Integration with existing IR FPA systems in large formats ($500 \times 500+$) will require a development effort of industry/university partners over next 5 years.
Major Commercial Applications	• Satellite IR remote sensing systems. • Drivers are increased information gathering capability and reduced payload weight.
Affordability	• Sensor costs are a declining portion of overall imaging systems because of cost reductions inherent in uncooled IR FPA technology as compared to HgCdTe cooled FPAs. • Not an issue.

RATIONALE

Key advantage is the ability to provide wavelength-resolved and polarization-resolved imagery in a no-moving-parts configuration. Reduces sensor system weight and complexity. Builds on successes of low-cost uncooled IR FPA programs funded by DoD. Enhances discrimination against countermeasures.

Target discrimination is enhanced by wavelength-resolved and polarization-resolved imagery. Specifically, avoidance of decoys and immunity to countermeasures for IR imaging and tracking systems. The technology of antenna-coupled IR sensors will allow integration onto the focal plane itself of the wavelength and polarization tuning functions. This accomplishes a no-moving-parts, low-mass solution to the need for hyperspectral imagers and imaging polarimeters, especially in small, airborne vehicles such as missiles, satellites and autonomous airborne platforms.

Military applications include surveillance systems, IR sensor suites for targeting, tracking, and missile guidance, imaging spectrometers, hyperspectral imagers, and imaging polarimeters.

Present uncoooled IR FPA development programs (primarily DARPA) are concentrated on realization of sensors operating at the background fluctuation limit of sensitivity, and near-equality with cooled sensor performance. This goal, which represents a fifty times increase in sensitivity relative to current uncooled IR sensors, must be achieved in order to realize the full benefits of polarization-resolved imagery.

Centers of technical development, including BMDO and Lockheed-Martin Corporation, have been major supporters of this research at UCF. DOE-funded programs at INEL, Idaho, and NIST, Boulder.

WORLDWIDE TECHNOLOGY ASSESSMENT

| Canada | ● | Finland | ● | Poland | ● | Russia | ● |
| Sweden | ● | Switzerland | ● | UK | ● | United States | ●● |

| Legend: | Extensive R&D | ●●●● | Significant R&D | ●●● | Moderate R&D | ●● | Limited R&D | ● |

Major Producers/Developers includes UK – Royal Signals & Radar Est.; Canada – Institute National Optique; Finland – Meteorex, Espoo Finland; Poland – Military Inst. of Technology, Warsaw.

SECTION 17.6—RADAR

Highlights

- Improved computational resources and efficient signal-processing algorithms are making it practical to field radars employing space-time adaptive processing (STAP) using large numbers of degrees of freedom for clutter and interference cancellation.

- Low-frequency systems for foliage penetration (FOPEN) and counter-stealth are under development, but radio frequency interference in the VHF/UHF bands and limits on spectrum allocation may limit utility.

- Space-based moving target indication (MTI) and synthetic aperture radar (SAR) systems providing operationally useful revisit rates will become more practical because of lower cost commercial component development for systems such as iridium or its successors.

- Low radar cross-section antennas and radomes, combined with power management and low probability of intercept waveforms, together are decreasing the detectability of stealthy aircraft and cruise missiles.

- Ultrastable solid-state transmitters have increased reliability, produced greater average power, and dramatically increased transmitter stability by replacing conventional tube technology. As a result, radar detection and tracking of sea-skimming and/or land-hugging low-observable missiles and other targets have significantly improved

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OVERVIEW

This section covers radar systems, the sensors most widely used by all military services. Radars are indispensable for a wide variety of military uses, being installed on the ground and in ships, aircraft, and missiles for search and localization of objects and installations of all types. Radar systems consist of power supplies, transmitters with final amplifiers, antennas, receivers, signal processors, and displays. Emerging radar technology developments include wide bandwidth operation, stability and ultralow noise for coherent operation; advanced software for signal processing; and automatic target recognition (ATR). Development activity includes solid-state transmit and receive modules integrated with antenna radiating elements for active aperture radar, and low radar cross section antennas. Millimeter-wave radars are now being implemented in missile seeker heads. High-power millimeter wave (94 GHz) radars are being considered for imaging nonmaneuvering aircraft and tactical ballistic missiles (TBMs) with inverse synthetic aperture radar (ISAR) techniques. Low frequency (VHF/UHF) radars are being developed for foliage and ground penetration and to counter stealth vehicle developments.

Critical technologies at the component level that support these advanced sensor developments and continue to be advanced include RF photonics, RF microelectromechanical systems (MEMS), and millimeter-wave integrated circuits (mmICs). GaAs continues to be the major microwave power generation and application material, but advances in InP, SiGe, SiC, and GaN will result in implementation of these materials in selected future applications.

There are a number of evolutionary, emerging technology developments in radar. Airborne moving target indication (AMTI) concepts increasingly depend on STAP advances. FOPEN radar is being explored for SAR and ground moving target indication (GMTI) missions. Bistatic systems continue to be of interest. Space-based AMTI, GMTI, and SAR are under consideration. Advances in target recognition remain key for reduction of fratricide and for effective employment of beyond-visual-range weapons. Ultra-wideband (UWB) radar systems are being employed for foliage/ground penetration and improved target recognition. Ultra-stable solid-state transmitters increasingly are replacing conventional tube technology. Over-the-horizon (OTH) radars, which do not require direct line of sight, have made significant advances. These are highlighted in the following tables. There are no known revolutionary, emerging technology developments underway.

RATIONALE

Radar is critical to a large number of military missions. Its ability to function during the day or night, relative immunity to weather, capability of localizing targets in range, and long range of operation make it the sensor of choice in many situations. At this stage of development, radar might be expected to be a mature technology. That is not the case for several reasons. First, as no sensor technology has appeared with its advantages and capabilities, radar has been pressed into new areas where it has not previously been used (e.g., detection of targets under foliage). Second, as stealth has made targets more difficult to detect and track, radar technology has been improved in an attempt to maintain performance. Third, electronic countermeasures (ECM) continue to remain a concern; it is being addressed with adaptive processing, low sidelobe antennas, and mainlobe cancellation techniques. Finally, the increasing capabilities of coherent, programmable sources, digital signal processing, and computing have allowed implementation of hardware and algorithms that could be only considered theoretically a few years ago.

A number of emerging radar implementations embody the technological advances discussed above. Low-frequency FOPEN systems take advantage of programmable sources to reduce interference to other electronic equipment in the VHF and UHF bands. Advanced signal processing and capable computers are key in FOPEN SAR, UWB target detection and recognition, bistatic systems for counter-stealth, and STAP. Migration into the space environment places severe limitations on weight and volume, while requiring improved performance. This improvement will be provided by increased microwave, photonic, and digital-processing components that provide an order of magnitude decrease in system weight, while operating in hostile electromagnetic and ionospheric environments. Ultra-stable solid-state upgrades to conventional tube technology lead to improved detection of low-observable missiles and other targets.

WORLDWIDE   TECHNOLOGY   ASSESSMENT

A number of countries currently manufacture radar equipment, but research in the areas discussed in this section is still limited to a relatively few countries. The break-up of the Soviet Union and the decreasing budget investments in military research in Russia have significantly reduced the thrusts from that region into new radar technologies. As might be expected, the major players are the large industrialized countries with commensurate military budgets. One specific exception is in the FOPEN area, where Sweden has actually led the world with the implementation of its experimental CARABAS HF–VHF airborne radar. A similar area of increased radar development focus is in the People's Republic of China, where a significant investment in low-frequency, bistatic radars for detection of low-observable aircraft has been openly observed and publicized. Of the technologies discussed, STAP is the most widely pursued because it is generally seen as critical to next-generation airborne-surveillance systems. ATR research is also being pursued in a number of countries because of the desire to employ beyond-visible-range weapons and concerns about fratricide. The remaining technologies are more niche technologies [countries that do not have a Joint Surveillance Target Attack Radar System (JSTARS) equivalent have little reason to consider FOPEN GMTI] and are being investigated only in a few places. Most of the downstream radar technologies utilize processing algorithms that are very computationally intensive. As commercially available chips increase in power while shrinking in size, rapidly improving computing capabilities will make many of the technologies discussed more practical for the smaller and less prosperous nations. Even so, most countries will remain purchasers of turnkey systems from major national or multinational manufacturers rather than attempt to develop their own technology.
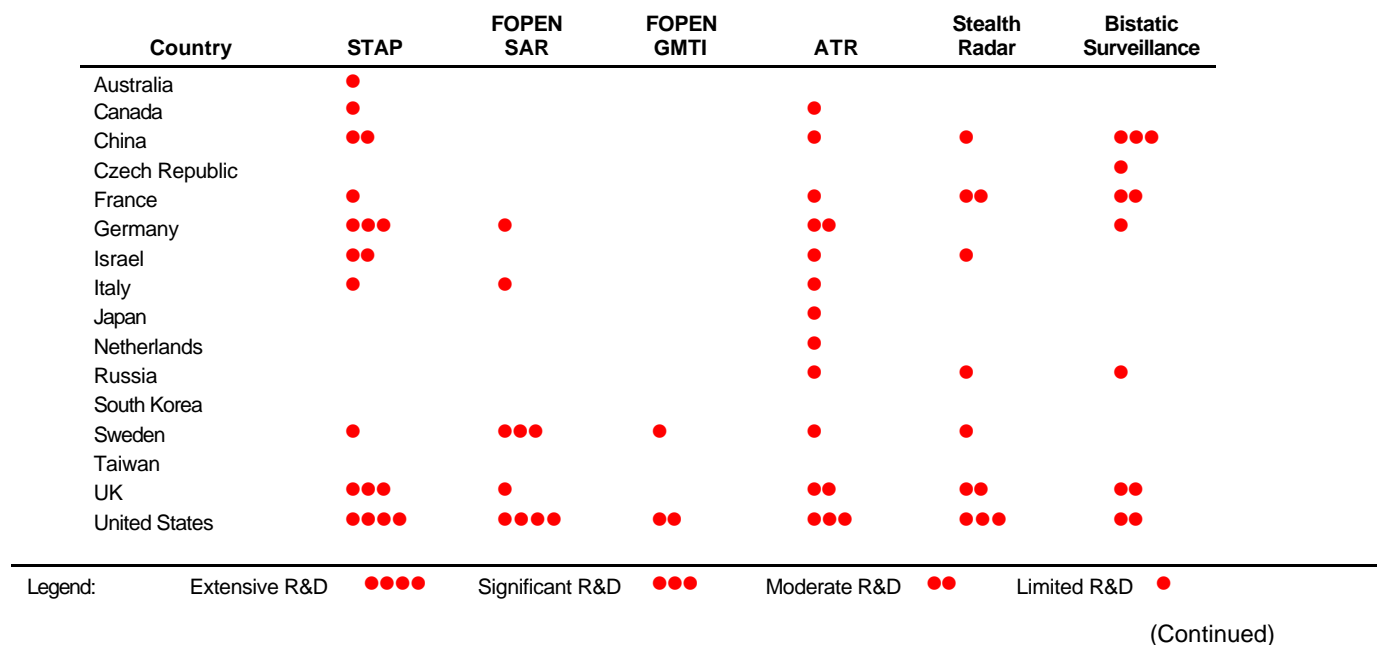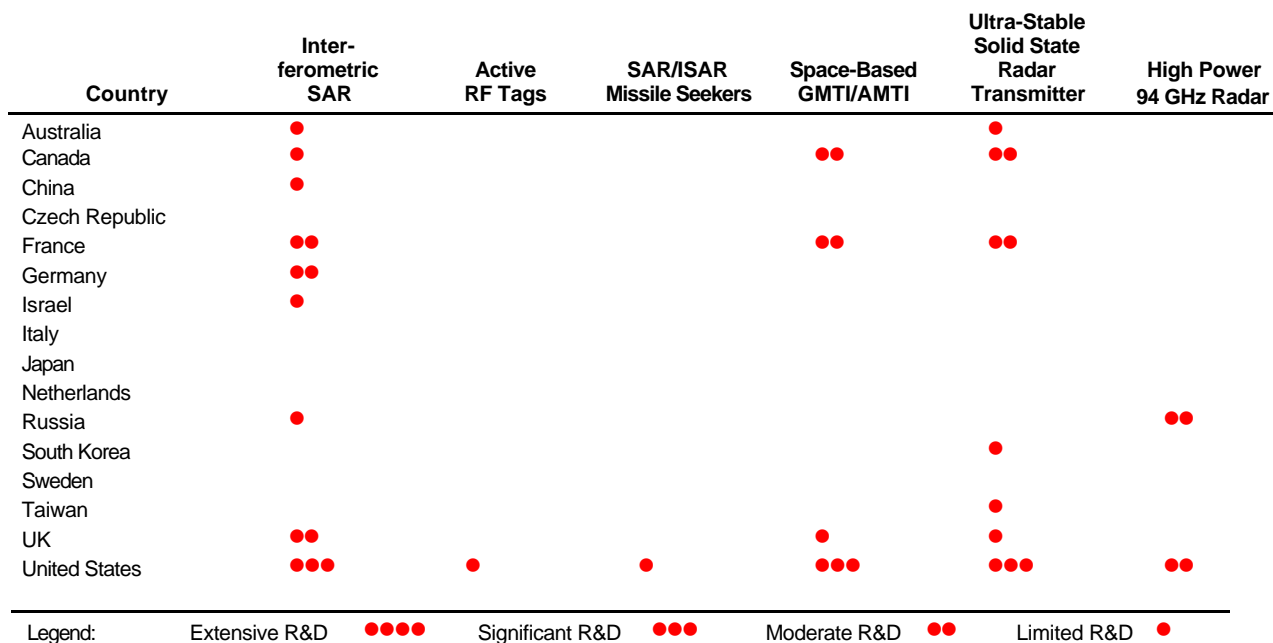
Country	STAP	FOPEN SAR	FOPEN GMTI	ATR	Stealth Radar	Bistatic Surveillance
Australia	●					
Canada	●			●		
China	●●			●	●	●●●
Czech Republic						●
France	●			●	●●	●●
Germany	●●●	●		●●		●
Israel	●●			●	●	
Italy	●	●		●		
Japan				●		
Netherlands				●		
Russia				●	●	●
South Korea						
Sweden	●	●●●	●	●	●	
Taiwan						
UK	●●●	●		●●	●●	●●
United States	●●●●	●●●●	●●	●●●	●●●	●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

(Continued)

Figure 17.6-1. Radar Systems WTA Summary

Country	Inter-ferometric SAR	Active RF Tags	SAR/ISAR Missile Seekers	Space-Based GMTI/AMTI	Ultra-Stable Solid State Radar Transmitter	High Power 94 GHz Radar
Australia	●				●	
Canada	●			●●	●●	
China	●					
Czech Republic						
France	●●			●●	●●	
Germany	●●					
Israel	●					
Italy						
Japan						
Netherlands						
Russia	●					●●
South Korea					●	
Sweden						
Taiwan					●	
UK	●●			●	●	
United States	●●●	●	●	●●●	●●●	●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

Figure 17.6-1. Radar Systems WTA Summary (Cont'd)

LIST OF TECHNOLOGY DATA SHEETS
III-17.6. RADAR

DATA SHEET III-17.6. STAP FOR AIRBORNE RADARS

Developing Critical Technology Parameter	>50 dB adaptive nulls in angle/Doppler space; >10 spatial degrees of freedom; real-time operation.
Critical Materials	Optical beamformer/signal distribution
Unique Test, Production, Inspection Equipment	Channel calibration; tracking, and compensation procedures/hardware, particularly those relating to real-time calibration/compensation during operation.
Unique Software	Efficient matrix and spectral signal-processing algorithms.
Technical Issues	Clutter sample support; discrete clutter suppression; effective suboptimum algorithms; wideband operation.
Major Commercial Applications	STAP for interference reduction in commercial point-to-point/cellular communications systems.
Affordability	High cost due to multichannel antenna/receiver, high-speed computation.

RATIONALE

Airborne radars routinely operate in high-clutter and dense jamming environments. Systems such as the Airborne Warning and Control System (AWACS) employ ultra-low sidelobe antenna technology to mitigate both clutter and jamming. As target radar cross section (RCS) levels of interest become lower and jamming technology becomes more sophisticated, antenna techniques alone are not sufficient to handle natural and man-made interference. STAP provides such potential because it samples the environment and adaptively forms filters in angle/Doppler space to optimally cancel both clutter and jammers. Because the system is adaptive, it provides much more flexibility under a wide range of circumstances; however, the flexibility comes at significant cost. The system must have sufficient degrees of freedom to cancel all interfering signals. An estimate of the covariance matrix of the interference must be formed, and that requires sufficient independent samples of the background. The mathematics connected with forming the optimum time and frequency weights is computationally intense and requires very large and very fast computers. Suboptimum techniques are being developed to lessen the computational burden and need for background sample support. As the bandwidth of the system or number of spatial degrees of freedom is increased, hybrid techniques that utilize optical processing combined with digital techniques are being developed.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●	Canada	●	China	●●	France	●
Germany(FGAN)	●●●	Israel	●●	Italy	●	Sweden	●
UK(DERA-Malvern)	●●●	United States	●●●●				

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

STAP research is widespread and pervasive because STAP is felt to be required for future-generation airborne surveillance radars. The United States leads significantly in research-grade hardware for data collection and exploration of practical STAP algorithm performance. Initial funding was provided by DARPA, with the focus of research in AFRL, NRL, and at MIT/LL. In industry, Northrop Grumman, Lockheed Martin, and Raytheon are all studying system concepts or fielding systems that make use of limited STAP (fewer than 10 spatial degrees of freedom). Other countries are more active in algorithm study, with Germany and UK having the most significant investments.

DATA SHEET III-17.6. FOPEN SAR

Developing Critical Technology Parameter	Wideband antennas and coherent transmitters and receivers covering significant portions of the VHF and UHF bands (e.g., 10–90 MHz and 150–550 MHz); coherent transmitter notching, radio frequency interference (RFI) cancellation hardware [pre-analog-to-digital (A/D) cancellation of >10 signals], wideband high dynamic range A/D converters (>500 MHz and >12 bits).
Critical Materials	None
Unique Test, Production, Inspection Equipment	Wideband and low-frequency antenna ranges (10–500 MHz)
Unique Software	Real-time image formation algorithms running on multiple parallel processors; effective false-alarm reduction algorithms [false-alarm rate (FAR) < 0.1/km^2].
Technical Issues	Radio-frequency spectrum allocation and interference mitigation, false-alarm mitigation, automatic target detection/classification, and target association between VHF and UHF images.
Major Commercial Applications	Topographic mapping under heavy vegetation (e.g., single- and double-canopy forest). Forestry surveys. Ground penetration for mine detection
Affordability	Relatively high cost because of tight specifications on multipolarization, wideband transmitters and antennas, and requirement for powerful but compact processors.

RATIONALE

Current SAR systems typically operate in the upper microwave bands and therefore are not capable of detecting targets hidden in forests or under tree lines because of the attenuation and backscatter of the signal provided by the foliage. VHF and UHF systems can provide FOPEN, but there are a number of very difficult technical challenges in developing high-resolution SAR systems in those frequency bands. First, the available bandwidth is not large. At VHF, less than 70 MHz of bandwidth is available, limiting range resolution to greater than 2 m. Even at UHF, bandwidths greater than 450 MHz are difficult to obtain, limiting range resolution to about 0.3 m. Obtaining fine cross-range resolution for these low-frequency systems is even more difficult. For example, a UHF radar would have to generate a synthetic aperture about 25 times longer than that of an X-band radar with similar resolution. Second, the UHF band, in particular, has large numbers of manmade interference sources (e.g., TV stations and military and civilian communications systems) that both limit the usable frequencies and provide receiver dynamic range concerns. Finally, current experimental systems demonstrate much higher FARs than would be tolerable in operational systems, and target detection/classification algorithms under development are computationally intensive. For that reason, polarimetric processing is likely required to achieve acceptable performance. A successful FOPEN SAR, however, would provide significant operational utility in areas such as Kosovo and Bosnia, where militarily important vehicles are often hidden under trees.

While research has been focused up to now on VHF/UHF solutions as described above, alternatives at millimeter-wave (mmW) frequencies (35 GHz and 94 GHz, for example) are currently being evaluated for future development. This concept would exploit gaps in the foliage cover and areas of thin coverage, plus short ranges from small, low-flying, low-speed, tactical unmanned autonomous vehicles, to produce high-resolution SAR imagery. Initial mapping measurements through single-layer canopies have been very encouraging, and a proposal has been submitted to DARPA for a more extensive measurement program. Attenuation levels through the canopies are not uniform and are generally tolerable for short-range radars in low-altitude UAVs. The mmW frequencies solve installation issues and provide bandwidth and reasonable frame rates in these relatively slow-speed conditions for high-resolution imagery.

WORLDWIDE   TECHNOLOGY   ASSESSMENT

Germany	●	Italy	●	Sweden	●●●	UK		●
United States	●●●●							

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

At the moment, this is a niche technology that has been actively explored only by the United States and Sweden. In the United States, efforts have been funded by DARPA, with participation by industry (Lockheed Martin, Raytheon), DoD Laboratories (AFRL and ARL), and FFRDCs (MIT/LL, JPL, and IDA). In Sweden, the National Defense Organization (FOA) has funded development of the CARABAS system and its modifications. Germany, Italy, and the UK have reported on limited FOPEN-radar sensor development.

DATA SHEET III-17.6. FOPEN GMTI RADAR

Developing Critical Technology Parameter	Multi-aperture UHF antennas, STAP algorithms for clutter cancellation, stable coherent oscillators (<–60 dBc/Hz, 5 Hz from the carrier).
Critical Materials	None
Unique Test, Production, Inspection Equipment	High-quality (a few meters CEP) positioning equipment (e.g., differential GPS combined with accurate on-board INS) for good target geolocation.
Unique Software	Real time (<1 sec processing time) STAP algorithms; software for registration of GMTI and SAR data, wavelength-diverse waveforms for enhanced target detection.
Technical Issues	RFI mitigation, false-alarm mitigation.
Major Commercial Applications	Detection of intrusions and illegal activity under jungle canopy by wide-area surveillance systems.
Affordability	Expensive because of large antenna and extensive computing required for STAP.

RATIONALE

The JSTARS radar has shown significant tactical utility in its ability to detect and track moving vehicles in the clear. In forested terrain, however, JSTARS GMTI capability is effectively nonexistent. A GMTI radar that could provide coverage into forests would be extremely useful; however, foliage attenuation is a strong function of frequency, increasing to values in the microwave regime that make a microwave FOPEN radar impractical. This forces operation of a FOPEN GMTI radar into the UHF band or below. The low frequency brings several severe technical challenges. Practical antenna size limitations limit the number of subapertures available and hence the number of spatial degrees of freedom available for STAP. The very low Doppler frequencies generated at desired minimum detectable velocities (e.g., a 1-m/s radial velocity at 300 MHz corresponds to a 2 Hz Doppler frequency) forces long coherent dwells for spectral separation of target and main beam clutter signals and places stringent requirements on transmitter stability.

WORLDWIDE TECHNOLOGY ASSESSMENT

Sweden	●	United States	●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Research in this area is just beginning. No country yet has a test-bed to evaluate potential system concepts. DARPA has an FY 2000 new start to do an end-to-end system study that will be undertaken by industry (likely Lockheed Martin and/or Northrop Grumman). Sweden is modifying the CARABAS II, under FOA guidance, to attempt to collect FOPEN GMTI data.

DATA SHEET III-17.6. RADAR-BASED ATR

Developing Critical Technology Parameter	Probability of correct classification levels greater than 90 percent in a multitarget, cluttered environment; ability to operate at detection level SNRs ($\approx$13 dB SNR); and real-time operation (classification within a few seconds of detection). UWB component technology and polarization diverse waveforms and antenna components are being developed to increase resolution.
Critical Materials	Some systems concepts use mmW frequencies to obtain very high resolution (a few inches) with modest percentage bandwidths (a few percent) and take advantage of increased Doppler sensitivity at the higher frequencies for imaging nonmaneuvering aircraft. High-power 94 GHz transmitters (~10 kW average power) must be developed.
Unique Test, Production, Inspection Equipment	RCS ranges capable of generating high-quality HRR and ISAR data (range and cross-range resolutions of a few inches) for use in features databases.
Unique Software	Robust ATR algorithms (>90 percent probability of correct classification); efficient signature storage and retrieval algorithms.
Technical Issues	Achieving high probability of correct classification; generation/storage of target signatures; recognition of target variants; and algorithms appropriate for each radar mode [high range resolution (HRR), SAR, ISAR]. Frequency allocation for UWB system operation.
Major Commercial Applications	None.
Affordability	Major additional expense is processing and signature storage. Some algorithms that require particular parameters (e.g., multiple polarizations or a given range resolution) might require radar design/modification.

RATIONALE

The advent of beyond visual range (BVR) air-to-air missiles and the concern about fratricide involving friendly aircraft or vehicles has raised the necessity for reliable noncooperative target ID. Because of the ranges typically involved, radar is a prime candidate for implementation of such systems. Research in radar-based ATR has focused on exploitation of target features derived from HRR, SAR, or ISAR data, depending on the application. In all cases, either measured or synthetically generated signatures have been required to provide a library of features used to distinguish among targets. Problems are compounded by variations within targets of the same type (e.g., aircraft with and without external stores or tanks with and without fender skirts) and variability of signatures as a function of frequency, polarization, and viewing angle. Different radar sensors produce very different types of data, making it unlikely that any "universal" ATR algorithms will be developed. Successful algorithms for air targets and ground targets may or may not be similar. Many algorithms do pattern or feature matching to known target signatures. This requires a large library to be available to cover expected target types and therefore sets a requirement for memory size and access speeds for operational timeline requirements.

WORLDWIDE TECHNOLOGY ASSESSMENT

Canada	●	China	●●	France	●	Germany	●●
Israel	●	Italy	●	Japan	●	Netherlands	●
Russia	●	Sweden	●	UK	●●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Target ID is an area being pursued at some level by a number of countries. The United States leads in this area because of fratricide concerns arising out of Desert Storm. Each of the services has target ID work underway, with much of the focus now on an integrated air picture or ground order of battle produced from fusing a number of sensors. A large number of academic and industry participants in DARPA and Air Force programs are investigating algorithms. Foreign efforts tend to be more limited to national defense research establishments (UK, Canada, and France), with industry participation in countries building or considering BVR weapons (Israel, France, UK, and Italy). In China the efforts are being carried out in the academic institutions; however, they are closely tied to the design centers.

DATA SHEET III-17.6. AIRBORNE "STEALTH" RADARS

Developing Critical Technology Parameter	Low RCS antennas (>20 dB below platform RCS specification); advanced frequency selective surface (FSS) radomes; low probability of intercept waveforms; and conformal antennas. Transmit/Receive module and radiating element designs for low RCS active arrays.
Critical Materials	High-strength, low dielectric constant, low-loss radome and substrate materials.
Unique Test, Production, Inspection Equipment	RCS ranges with sufficient sensitivity to provide both diagnostic and total RCS measurements at component and subsystem levels (noise floor <−80 dBsm); CAD/CAM for accurate, cost-effective manufacture of multilayer radomes. High uniformity T/R Module and radiating element manufacturing.
Unique Software	Antenna and FSS design software combining numerical electromagnetic codes with design optimization software; conformal antenna design and optimization software. Integrated antenna/forebody RCS analysis codes. Adaptive signal processing for waveform intercept reduction.
Technical Issues	Achieving very low signature while maintaining performance; design of difficult to detect [low probability of intercept (LPI)] waveforms; and power management to reduce probability of intercept.
Major Commercial Applications	None.
Affordability	Systems will be significantly more expensive than conventional radars.

RATIONALE

For an airborne platform shaped for a low RCS signature, antennas of the sensors can be the dominant contributors to the residual RCS. In addition, if the platform desires to use radar for guidance, surveillance, or fire control, it invariably gives its presence and perhaps its position away to opponent electronic support member (ESM) systems. Thus, stealth radars must provide a low RCS and an LPI waveform if they are not to degrade the carrying platform's capabilities. Because shaping is the major technique through which stealth platforms control their signature, conformal antennas have the potential to naturally provide low RCS; however, impedance matching within the antenna is critical to stealth performance. Therefore, the use of frequency-selective surface radomes that pass in-band frequencies but reflect out-of-band signals can make the antenna design task tenable. Those radomes must be designed in concert with the antenna to insure that cross-polarized pattern perturbations are minimized and that antenna tracking capabilities are not jeopardized. In addition, high uniformity of radiating elements, modules, and circulators (where required) is necessary to achieve low RCS.

WORLDWIDE TECHNOLOGY ASSESSMENT

China	●	France	●●	Israel	●	Russia	●
Sweden	●	UK	●●	United States	●●●		

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

In general, information on research in the stealth area is tightly held. Released information in the United States pertains mostly to platforms such as the B-2, F-22, JSF, and Comanche. In that arena, efforts have been undertaken by the major U.S. Aerospace firms (Lockheed Martin, Northrop Grumman, and Boeing) and supporting radar contractors (Raytheon and Northrop Grumman). Design information on active array TR modules, mmICs, and radiating elements is particularly sensitive and protected. Efforts in other countries are not well publicized except for

French cruise missile vendors advertising low-RCS cruise missiles containing radars and some design details on Swedish Viggen and European Eurofighter design (UK, France, and Germany).

DATA SHEET III-17.6. BISTATIC SURVEILLANCE RADARS

Developing Critical Technology Parameter	Electronically scanned, multiple-beam antennas for "pulse chasing," high (>100 GOPS) throughput data processors for coherent processing, and high dynamic range receivers (>100 dB).
Critical Materials	None.
Unique Test, Production, Inspection Equipment	Ultra accurate Time, frequency, and navigation instrumentation to determine waveform location and timing to 10's of picoseconds accuracy.
Unique Software	Matched-filter algorithms involving illuminator waveform; target state determination (location, heading, speed) software; antenna control/beam scanning software; and STAP for bistatic clutter mitigation.
Technical Issues	Coordination of illuminator and receiver and accurate target location determination. Antenna design for multiple beams and adaptive processing. System dynamic range (>100 dB to >120 dB) for separating direct-path illumination from signal and clutter.
Major Commercial Applications	None.
Affordability	For a bistatic radar that hosts off of a noncooperative illuminator, transmitter costs are saved and "radar stealth" is inherent. The receiver/processor, however, will be much more complex than for a standard radar, offsetting much of the cost advantage. If a special illuminator, as well as a receiver, must be developed and built, costs will be greater than for a similar monostatic radar.

RATIONALE

Although bistatic radars mostly exist today in the form of semi-active homing missiles, research continues in a number of countries to expand their utility. Bistatic radar concepts under investigation for surveillance operations include those that host off a cooperative illuminator and those that employ noncooperative illuminators. Cooperative illuminators might include ground-based, airborne, or space-based assets. Noncooperative illuminators might include FM radio stations, TV stations, or monostatic radars in the area. Bistatic radar has two significant potential advantages. The first is that the receiver can be stealthy. For a system that hosts off radio or TV stations, the adversary may not even know that radar is being employed. Even where the illuminator is known as such, bistatic operation can add to the stealth potential of aircraft (manned and unmanned), which need employ only a receiver. The second advantage is the counterstealth and survivability potential of bistatic radar. Current stealth platforms are designed to have low signatures against monostatic radars. Bistatic radars, particularly those with large bistatic angles, are likely to see an enhanced signature from stealthy platforms. In addition, for those systems that host off illuminators in the VHF and UHF bands, such as radios and TVs, low-frequency operation will also provide enhanced signatures.

On the other hand, the technical challenges in producing operationally useful bistatic surveillance systems are formidable, and hence these radars are excellent candidates for improvement in technology. For narrow-beam, scanning illuminators, the receiver antenna must electronically adapt to the transmit beam so that the receiver is looking at potential targets at the correct time. Multi-beam antenna architectures, an attractive alternative to a fast scanning approach, are being pursued as an outgrowth of the STAP research described in a previous subsection. The receiver system arrays are being partitioned into multiple subarrays to obtain multiple degrees of freedom for the STAP clutter and jamming suppression capabilities. These subarrays produce broad-beam patterns which subtend a large number of transmit pulse positions. The subarray outputs are digitally combined in beamforming algorithms during the STAP operations to form multiple, simultaneous, high-gain, narrow beams across the broad subarray patterns plus the appropriate nulls to cancel clutter and jamming. Although this lessens the severity of the pulse chasing problem, it also combines the technical challenges of STAP and bistatic processing into a common

development risk. Systems using omnidirectional illuminators such as radios and TV stations must have very high dynamic range receivers (>100 dB, and in some cases, >125 dB), because the radar may be forced to look near an illuminator direction to detect targets of interest. Processing is complicated, and it is not clear that bistatic radars can reliably provide fire-control-grade solutions for all engagement geometries of interest, without a very large number of simultaneous beams and attendant cost of adaptive signal processing. Fire-control arguments aside, bistatic radar does have acknowledged potential for performing the surveillance function.

The cooperative bistatic SAR spot mode case is much easier than the air surveillance case. The transmit-and-receive beams are aimed at a common spot in GPS coordinates for the SAR image frame time, so pulse-chasing issues are solved by maintaining a common timing reference between the bistatic transmitter and receiver. Atomic clock references and common GPS coordinates and timing references provide a means for maintaining the common timing references. Northrop Grumman, for example, demonstrated a 1-m SAR over tens of kilometers in a 1998 independent research and development (IR&D) demonstration with these techniques. Combining multiple sequential spots creates a SAR area coverage capability. Similar concepts extend to bistatic GMTI applications.

WORLDWIDE   TECHNOLOGY   ASSESSMENT

China	●●●	Czech Republic	●	France	●●	Germany	●
UK	●●	United States	●●				

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Research in bistatic radar in the United States has been ongoing at AFRL for a number of years, with Syracuse Research Corporation as the primary contractor. Much of that work has focused on use of existing military radars (e.g., AWACS) as the illuminator. However, bistatic passive coherent location technology has also been pursued by DoD and industry, often with the goal of hosting off FM radio or TV transmitters as illuminators. The Lockheed Martin Silent Sentry system is an example of such technology. China is showing research interest in bistatic radars based on publications from academics. Institutions include the National University of Defense Technology, Xidian University, and the Beijing Institute of Radio Measurement. In addition, China has collaborated with the French to install an experimental system for development testing. The Russians are marketing a forward-scatter fence radar for detection of stealth aircraft. Called Struna-1, it was built by the Nizhny Novgorod Radiotechnical Research Institute. The UK is also exploring systems similar to Silent Sentry at the Defence Evaluation and Research Agency (DERA), Malvern. The Czech Republic is exploring a passive system called VERA, which is similar to Silent Sentry.

DATA SHEET III-17.6. HIGH-PRECISION INTERFEROMETRIC SAR PLUS GLOBAL POSITIONING SYSTEM (GPS) FOR ACCURATE TOPOGRAPHIC MAPPING

Developing Critical Technology Parameter	Multiple-aperture SAR with sufficient separation to give required resolution and differential elevation accuracy [digital terrain elevation data (DTED) level 5, 1-m posts and sub-foot accuracy]; precise aircraft geolocation knowledge; and precise antenna pointing. Combining two frequencies of operation (UHF and C-Band) for bald Earth mapping and terrain feature classification.
Critical Materials	None.
Unique Test, Production, Inspection Equipment	Differential GPS and inertial transfer alignment to hold fractional wavelength and microradian accuracy on direction of arrival measurements.
Unique Software	Efficient and accurate phase unwrapping algorithms. Phase center measurement and transfer alignment to enable high accuracy, absolute height measurement.
Technical Issues	Precise geolocation and velocity of collecting aircraft (errors <1 m) and precise antenna relative location and velocity information (fractional wavelength accuracy).
Major Commercial Applications	Wide potential use for terrain use planning; road route considerations; hydrological analyses.
Affordability	Requires second SAR channel and high phase accuracy hardware, but relatively affordable. FOPEN interferometric synthetic aperture radar (IFSAR) requires second frequency and polarization channels.

RATIONALE

The advent and widespread use of GPS has improved location precision measurements to the point that GPS is now considered sufficiently accurate for targeting. However, to effectively make use of that accuracy, the surface topography in the targeted area must be precisely known. Single-pass IFSAR technology is widespread, but the resolutions and navigation accuracy required to support level 5 DTED are not. Support of autonomous homing weapons that depend only upon geolocation accuracy for effectiveness will require very accurate topography of the target area. The only practical way to achieve such accuracy with the high area coverage rates desired is through single-pass SAR interferometry.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●	Canada	●	China	●	France	●●
Germany	●●	Israel	●	Russia	●	UK	●●
United States	●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Both NASA and DoD are funding research in the United States. DARPA funded an interferometric SAR program with ERIM and JPL leading to the commercial IFSARE system. JPL has flown several interferometric systems for NASA, doing both two-pass and single-pass interferometry. In addition, JPL has developed a dual-frequency FOPEN IFSAR system for DARPA (GeoSAR). The Discoverer II space-based radar is planned to collect DTED level 5 data. To date, other countries have mostly demonstrated two-pass interferometry, with the exception of Germany and more recently Australia. However, commercial, as well as military applications are likely to drive continued development in this area.

DATA SHEET III-17.6. ACTIVE RF TAGS

Developing Critical Technology Parameter	Small (<20 mm³), low-power (<5 mW), personnel-portable identification of friend or foe (IFF) transponders; appropriate encrypted interrogation waveforms commensurate with radar operation/performance.
Critical Materials	High-energy-density batteries (>500 Wh/L in packages <10 mm³).
Unique Test, Production, Inspection Equipment	None.
Unique Software	Encryption system (low data rate, <1 kb/s).
Technical Issues	Size and weight of transponders and security of codes when transponders captured.
Major Commercial Applications	Commercial cellular market. Tracking of rail cars within marshalling yards or trucks within depots.
Affordability	Individual responders should be inexpensive; however, a very large number is required.

RATIONALE

Reducing the probability of fratricide has become increasingly important in recent military operations. RF tags would allow radar systems to incorporate a coded signature in a portion of the transmitted waveform. That signal could trigger transponders carried by troops and provide a coded IFF reply. The major technical challenges to this technology are the design of a transmitted code compatible with the radar waveform; the design of a transponder capable of operating at the frequencies of all possible radars that might trigger it, while remaining low-power and lightweight; and the issue of code security with a very large number of deployed transponders, some of which will inevitably fall into enemy hands.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States ●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

This technology is in a very early phase. DARPA is currently supporting studies in the area. No efforts in other countries are known.

DATA SHEET III-17.6. SAR/ISAR MISSILE SEEKERS

Developing Critical Technology Parameter	Very small (<1,500 cm^3), lightweight (<5 kg) active radars, missile-electronics compatible SAR/ISAR signal processors, and SAR/ISAR-based ATR algorithms.
Critical Materials	None.
Unique Test, Production, Inspection Equipment	None.
Unique Software	ISAR image-formation algorithms for unknown target motion; appropriate ATR algorithms for desired target classes.
Technical Issues	Weight, size, and power constraints provided by missile limitations, trajectory planning for SAR imaging, and ISAR image formation with unknown target motion. Low-cost mmW smart antennas.
Major Commercial Applications	None.
Affordability	At least a factor of 2 more expensive than conventional active seeker because of signal-processing requirements. Differential will reduce as processing becomes less expensive.

RATIONALE

In recent conflicts one major goal has been to precisely deliver munitions to the target with a minimum amount of collateral damage. Another goal has been for munitions to autonomously select the desired high-value target among a group of possible targets. For either mission, a missile seeker that can form 2–D images provides significant additional information for target selection. Against fixed targets, SAR imaging could be used for map matching during missile ingress and for precise ATR and target selection. Against moving targets, ISAR imaging could be used to provide input to ATR algorithms to more confidently select desired targets. In addition, seeker-processed data could be linked to remote operators for target verification and battle damage assessment (BDA). The technology challenges revolve around packaging a useful radar and its processor in available space in a missile, in autonomously providing flight paths that produce useful images, in development of affordable mmW antenna technology, and in effectively using the output data.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

This technology is in its infancy. Low-level studies are underway in the United States, funded by AFRL. No known work is underway outside USA.

DATA SHEET III-17.6. SPACE-BASED GMTI/AMTI

Developing Critical Technology Parameter	Large (>50–500 m^2), lightweight (4 kg/m^2), electronically steered antennas; high-efficiency T/R modules (70 percent at X-band). Photonic signal distribution and beamforming technologies. Reliable microelectromechanical systems (MEMS) components for low-loss, lightweight antenna control.
Critical Materials	Improved batteries (150–175 Wh/kg and 500 Wh/L); improved efficiency solar cells (>25 percent); lightweight power conditioners and support structures; high-efficiency, radiation-tolerant T/R modules, new materials, and device structures for receiver power reduction. Lightweight, high-strength, thin-film materials for deployable antennas.
Unique Test, Production, Inspection Equipment	Commercial assembly-line production techniques to significantly reduce single satellite costs for large constellations; thin-film RF component assembly and test for lightweight deployable arrays; and standardized spacecraft bus designs.
Unique Software	STAP software for real-time clutter cancellation and jammer nulling and on-orbit target detection and classification software to reduce downlink data rates. Integration of SAR/ISAR and GMTI/AMTI waveforms and processing.
Technical Issues	Primarily an affordability issue. Capability exists to build and launch useful satellites. Required large constellation sizes make current costs unaffordable.
Major Commercial Applications	GMTI: traffic monitoring; AMTI: air traffic control over oceans.
Affordability	Constellation costs are projected to be very high.

RATIONALE

AWACS and JSTARS have proven their worth in a number of recent operations; however, both are generally required to stand well back of the forward edge of the battle area (FEBA), limiting their access to possible target areas of interest. Moving AMTI and GMTI capabilities to space provides a number of benefits, a major one of which is deep access. For low-Earth orbit (LEO) satellites, however, orbital velocities are around 7 km/s, spreading sidelobe clutter into the Doppler region of targets of interest. Thus, STAP processing will be required for clutter cancellation. In addition, with satellite orbits easily determined, STAP will also be required to cancel high-power, high-gain jammers that could be aimed at the satellite. Although the optimum frequency for GMTI is likely around X-band, AMTI systems would prefer operating at much lower frequencies (e.g., VHF or UHF). However, ionospheric scintillation effects at the lower frequencies may significantly degrade performance. For either type of system, trades will have to be made between many smaller systems in LEO orbits or fewer systems in higher orbits to achieve the desired coverage. For a given orbit, required revisit times will drive constellation sizes, and area coverage rates will drive satellite size. In any event, very large and affordable apertures will be required, as will large (by satellite standards) prime power levels. Antennas are a major cost challenge. Both will drive technology requirements for structures and power to meet needs cost effectively. With the development of suitable waveforms and on-board processing techniques, these satellites can achieve the dual functionality of providing both SAR/ISAR and GMTI/ATMI information via relatively narrowband links to ground stations.

WORLDWIDE TECHNOLOGY ASSESSMENT

Canada	●●	France	●●	UK	●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The Discoverer II GMTI and SAR program that plans to launch two satellites in the 2003–2004 time frame principally represents U.S. efforts in this area. The Air Force, DARPA, and NRO jointly fund that project. The United States, Canada, and the UK have a joint technology exchange program studying space-based AMTI radar.

Canadian participation is principally through DREO, UK participation is through DERA Malvern, and the United States is represented by AFRL. DREO plans some limited GMTI experiments using RADARSAT 2, which is primarily designed as an SAR. A European consortium is working with JPL on future low-cost radar satellites (may have multiple channels for some MTI performance). AFRL is also sponsoring space-based antenna work in its TRAM program. The long-term goals of this program address both GMTI and AMTI functions. The latter is to be realized at low frequency, UHF, or L-band.

DATA SHEET III-17.6. ULTRA-STABLE SOLID-STATE RADAR TRANSMITTER

Developing Critical Technology Parameter	Fourfold increase in amplifier reliability, highly redundant approach, greater average power than tube version, dramatic increase in transmitter stability.
Critical Materials	Supply of transistors with uniform characteristics.
Unique Test, Production, Inspection Equipment	Taguchi methods and robust development techniques within integrated product team with customer and key suppliers as full-time participants.
Unique Software	Built-in-test equipment to monitor amplifier health.
Technical Issues	Transistor uniformity and divider/combiner design approach.
Major Commercial Applications	Replacement for high-power tube transmitters with improved reliability.
Affordability	Reasonable costs because of unique test and production methods.

RATIONALE

Solid-state radar transmitters have replaced aging tube technology, leading to improved reliability, maintainability, and availability. In the United States, this has been accomplished by combining the outputs of 160 transistor amplifiers with low-loss microwave combiners. As a result, average power increased, reliability has grown fourfold, and the stability has increased dramatically.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●	Canada	●●	France	●●	South Korea	●
Taiwan	●	UK	●	United States	●●●		

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Other countries such as Canada, UK, Australia, Korea, and Taiwan have fabricated subsystems, such as power divider/combiner, which make up the solid-state transmitter. Improvements are expected in the next 5 years.

DATA SHEET III-17.6. HIGH-POWER 94-GHz RADAR

Developing Critical Technology Parameter	A 10-kW average power 94-GHz radar is under development for ISAR imaging of non-maneuvering aircraft and TBMs.
Critical Materials	Gyroklystron, duplexer, overmoded waveguide, and precise antennas.
Unique Test, Production, Inspection Equipment	High-power test equipment.
Unique Software	Target classification algorithms for aircraft and TBMs.
Technical Issues	Weather penetration, Doppler sensitivity, weight, and size.
Major Commercial Applications	None.
Affordability	High cost, because of limited availability of components at this frequency.

RATIONALE

Airborne radars require the ability to classify targets at extended ranges to take advantage of long-range air-to-air missiles. ISAR techniques work well against ships, but they have been less successful against non-maneuvering aircraft because of the lack of motion to generate the synthetic aperture. At 94 GHz there is enough Doppler sensitivity to generate a synthetic aperture with aircraft experiencing only air turbulence. The frequency 94 GHz can also be used to generate ISAR images to discriminate between reentry vehicles, debris, and decoys in counter TBM applications.

WORLDWIDE   TECHNOLOGY   ASSESSMENT

Russia   ●●   United States   ●●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

This technology has been actively explored by the United States and Russia. In the United States, research has been funded by DARPA and ONR, with participation by industry (Communications and Power Industries, General Atomics, and Diversified Technologies), DoD Laboratories (NRL), and FFRDCs (MIT/LL).

SECTION 17.7—LAND MINE COUNTERMEASURES

Highlights

- Nuclear and chemical residue technologies that detect the mine main charge explosive will reduce the false-alarm rates.

- Use of hyperfine interactions technology (NQR) to identify explosive chemicals directly can be used to detect explosive compounds in nonmetallic mines.

- Use of imaging techniques to obtain more reliable information from GPR and EMI techniques will help to reduce false alarms while concomitantly enabling the detection of both metallic and nonmetallic mines.

- Use of ATR to fuse EMI, GPR, IR, and explosive detection signals will facilitate the use of multisensor fusion on vehicle platforms.

- Use of genetically improved bees (or other insects) to identify specific explosive compounds that leak from land mines and unexploded ordnance (UXO).

- Innovative use of dogs and other animals to locate explosives to provide explosive detection at vehicle speeds.

- Miniature shape charge arrays that attack the mine main explosive charge will provide high probabilities of mine kill.

- Directed-energy technologies that either spoof or disrupt mine electronic fuzes will be used to spoof advanced electronic fuzes.

OVERVIEW

This section addresses developing technologies for mine and minefield detection and for mine and minefield neutralization. A variety of technologies being developed for both mine detection and mine neutralization are compatible for use in airborne, ground vehicle, and soldier platforms. We therefore address six technology groups: **standoff-minefield detection, vehicle-mounted detection, hand-held detection, standoff neutralization, vehicle-mounted neutralization, and man-portable neutralizers**.

The technologies discussed in this section fall into two categories. The first category contains techniques that have been in the development stage for some time and have been used in other applications very successfully, but their support for mine countermeasures has not been justified to date. We expect major improvements in the future either because of a better understanding of the ground environment, a change in the operational procedure, or synergistic effects with other sensors (examples are radar and IR). In the second category are technologies that have been successfully tested in the laboratory and are being modified for field work (an example is NQR) or those technologies that are still in the laboratory testing phase (genetically modified bees and artificial noses).

The mine and minefield detection problems are paced by the large variety in shape, size, and construction of land mines; the variety of environments that they are located in; and also by the amount of clutter in which they are dispersed. EMI techniques have long been used to detect metallic mines, but these techniques detect many forms of metallic clutter found in the ground. New techniques to evaluate the induction decay times peculiar to different targets are being investigated as a means of separating clutter from mine targets. Stepped-frequency GPRs that exhibit high probabilities of detection (higher than 90 percent) of plastic antitank mines and increasingly higher detection rates (70 percent) of the small antipersonnel land mines have been developed. Unfortunately, both active and passive IR techniques have been in the development stage for some time for mine detection. Their appeal has been in the potential to identify minefields from airborne platforms. Unfortunately, the mine signature changes during the diurnal cycle. This variation, coupled with poor performance from current ATR programs, has resulted in

investigations into more complex approaches like hyperspectral systems to identify more robust target-recognition techniques. Nuclear detection using thermal neutrons to excite prompt gamma response from nitrogen and nitrogen compounds works well for large antitank mines but is limited in its ability to find the smaller antipersonnel mines. NQR techniques have shown promise in detecting explosives containing RDX such as Comp B. More sensitive techniques are being developed to see the weaker resonances of the most common mine explosive, trinitrotoluene (TNT). Technologies that emulate the biological sensory organs to detect the chemical residue of explosives are being investigated to discern the sensitivities required and the performance in a wide range of backgrounds. Biotechnology approaches are being developed that utilize bioluminescence associated with reaction with explosive compounds. ATR is the major enabling technology for all of these explosive-detection technologies. Progress is being made in fusing the EMI, GPR, IR, and nuclear detection methods on ground-vehicle platforms.

Traditional approaches to mine neutralization utilize mechanical plows, rollers, and flails to clear mines or activate simple pressure plate mines. Modern mines employ advanced electronic sensors and can attack targets and neutralizers from standoff distances. To counter these new mines, two approaches are being developed. Nets that use shaped charge warheads can be propelled over a section of the minefield and then detonated. The shaped-charge warheads detonate the mine main charge, and a path is cleared through the minefield. Successful deployments of these nets has been recently accomplished. A second approach used to deal with electronic fuzed-mines is the use of directed energy to spoof or disrupt the mine fuzes.

RATIONALE

Generally, minefields are only deployed with indirect- and direct-fire weapons. The primary purpose of the minefield is to cause delay in enemy operations. Technology approaches to mine detection and neutralization must be compatible with high-tempo operations. Historically, detection and breaching of minefields has taken 6 to 12 hours under direct and indirect fire. IR and wideband radar technologies capable of locating minefields from aerial platforms are needed for standoff detection of minefields. Rocket-propelled nets using shaped charges are needed to achieve a rapid breach through detected minefields.

Increasingly, the United States has been involved in peacekeeping missions in which troops are exposed to mines that were previously placed in other nations. Close-in detection and neutralization technologies that are robust and provide high probabilities of detection, Pd, and probabilities of neutralization, Pk, are needed. Slower, more deliberate systems that use a broader spectrum of technologies can be used.

BACKGROUND

Mines serve three functional roles on the battlefield: (1) they cause delay leading to a loss of synchronization and loss of surprise; (2) they damage or destroy armored vehicles and dismounted soldiers; and (3) they cause fear and anxiety even with battle-seasoned troops. Mines and minefields are generally placed so that they are covered by direct and indirect fire. The longer the offensive force takes to get through the mines or minefield, the greater the casualties inflicted on the offensive force.

Mines are historically deemed a defensive weapon, but modern warfare also has placed a premium on the use of flank-protection minefields to allow attacking forces to marshal sufficient force ratios (3:1 or higher) necessary to win offensive operations. In the case of the more traditional maneuver type of warfare, the emphasis in countermine operations is speed of detection, neutralization, marking, and breaching.

In recent years, mines have turned from being a military weapon into a weapon that at times is indiscriminately used against civilians. Political turmoil can lead to the use of mines by different political protagonists for specific political or economic gains. U.S. forces are increasingly being deployed in peace-keeping missions to areas of political unrest. In these types of situations, the mine is the weapon of choice for the smaller power or land force. The countermine requirements for these situations require high probabilities of detection and neutralization and low false-alarm rates. These requirements sometimes allow a different set of technologies to be applied for these types of applications.

The fundamental questions addressed in these analyses are the relationship of the speed of detection and neutralization to the probability of detection of neutralization. Second, the technical risks associated with each technological approach must be related to its potential payoff, that is, the transition of a technological approach into a fielded system that meets user requirements. This assessment also must address the relative maturity of various technology approaches, particularly with respect to evolving capabilities in the United States and other nations.

1. The Role of the Speed of Search

For maneuver warfare, the speed of the detector is paramount. The rate at which mines and minefields can be detected and marked has a significant impact on the timelines of the maneuver force. Relatively few technologies are compatible with the requirements for high-speed search of large land areas from airborne vehicles. In fact, many technology approaches can only be effective in the immediate vicinity of each mine.

Figure 17.7-1 shows the probability of mine detection as function of speed of search. In Figure 17.7-1, the speed of search ranges over 6 orders of magnitude, from basically a stationary examination of an area to an aerial survey. The tail of the arrow represents the current state of the technology, and the arrowheads indicate the direction that new research activity can advance. Physical process limitations, background noise barrier, and clutter barriers are also shown.

Clearly, the technologies that cannot sustain a speed of search in the hundreds of square meters per minute would not be compatible with airborne systems used to remotely detect minefields. On the other hand, slower detection technologies such as neutron activation and chemical detection could be used as confirmatory sensors for a near-field interrogation to find buried mines.

We can define the detection quotient, DQ, as the ratio of true detections to the total mines present multipled by the ratio of true detections and the sum of true detections and false detections:

$$DQ = \text{Detection Quotient} = \{T/N\}\{T/[T+F]\},$$

where T = the total number of true detections, N = the total number of mines present; and F = the number of false identifications. In the limit of zero false detections, this definition gives the DQ = true/total. In the limit of high false detections, the DQ decreases to zero even if all the mines are detected. Figure 17.7-2 shows a plot of DQ where the total numbers of mines present is 50. The total number of true detections is plotted on the abscissa and ranges from 0 to 50. The curves are labeled with the number of false identifications, which range from 0 to 50.
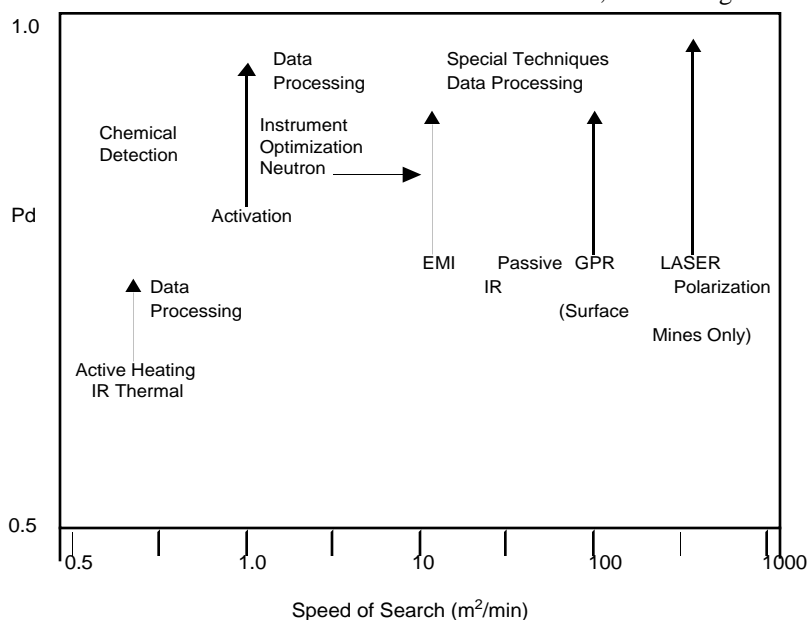

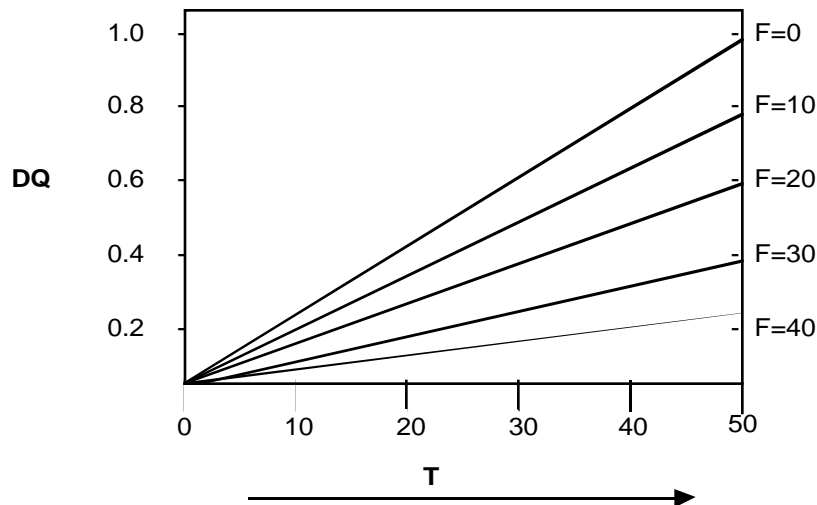**Figure 17.7-1. Mine Detection Technologies and Projections**

Figure 17.7-2. Detection Quotient as a Function of Mine Detections and False Alarms

The sources of the signals used to detect mines is a method of classifying technology approaches, particularly with respect to selectivity. The most desirable techniques are those that detect specific chemicals or elements that are intrinsic to mines. Since all mines have a main explosive charge, which is generally the largest single component of the mine, detection of main charge explosives should lead to the highest discrimination and lowest false-alarm rates. Nuclear techniques like neutron activation can detect specific atoms contained in the explosive chemical but not the chemical species. However, nuclear techniques can be used in a one-sided geometry and as part of a remote configuration. Techniques that depend on material discontinuities (conductive mine in contact with insulating Earth or vice versa) and detect the casing of the mines are subject to clutter and false-alarm problems. GPR, passive IR, and EMI are examples of these type of detectors. Other techniques that depend on the properties of the bulk mine material (active heating, IR, acoustic) or ground perturbations (radar) become less and less selective and are more prone to false alarms. Table 17.7-1 summarizes the technologies analyzed and places them on a scale of relative selectivity.

Table 17.7-1. Mine Selectivity for Various Technologies

	Increase in Selectivity			
Technology	**Perturbed Soil**	**Bulk Mine Properties**	**Specific Atoms**	**Explosive Chemical**
Neutron activation	No	Yes	Yes	No
Chemical spectroscopy	No	Yes	Yes	Yes
Biochemical	No	Yes	Yes	Yes
Radar	Yes	No	No	No
GPR	Yes	No	No	No
EMI	Yes	Yes	No	No
Passive IR	Yes	No	No	No
Active Heating (IR Thermal)	Yes	No		No
Acoustic	Yes	Yes	No	No

Those techniques that can provide high-resolution images are also very desirable because, on the basis of shape, one may be able to reduce the false-alarm rate. Even if the straight signal is not selective, if it can be used to produce images, then the image may be more revealing and thereby increase the selectivity. Techniques that measure the signal from the casing and give a high S/N may be used to produce images. Figure 17.7-3 is a notional graph that relates the effectiveness of detection to the speed of search.
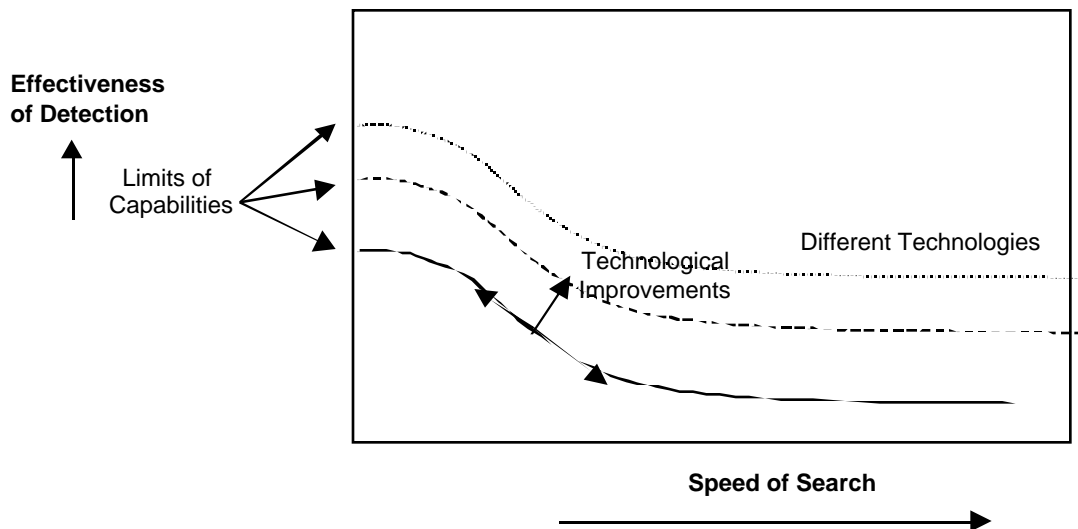
Figure 17.7-3. Effectiveness of Detection at Increasing Speeds

As the speed of search increases, the detection capability decreases, as shown by the solid curve. As the speed of search is decreased, the detection capability increases but eventually reaches a limit of detection capability. Technological improvements could increase the detection as a function of speed of search to produce a higher capability at the low speed limit (see the dashed curve). The dashed curve may actually represent a limit in the improvements that can be achieved with the particular technology because of clutter or inherent instrument limits. To further increase the detection (see the dotted curve) at a particular search rate, a different technique may have to be employed.

Computing effectiveness of technologies and system concepts requires some selection of pertinent parameters:

- Discrimination/selectivity
- Search rate
- False-alarm rate
- Probability of detection
- Sensitivity
- Missed targets.

These parameters could be related through a theory of measurements or through some theoretical model which would involve an assumption about the environment and sources of clutter as well as instrument settings that determine the threshold for signal acceptance. A low threshold would result in missed targets. With a given instrument one could expect an increase in false alarms with an increase in sensitivity. Along with these trends, one would also expect that a requirement of increased discrimination would result in a necessary reduction of the search rate.

In current systems that we have analyzed, there is nothing that can solve all the problems inherent obtaining high probabilities of detection with very low false-alarm rates. The preferred approaches and technologies depend on the kind of targets that are being interrogated, the environment in which they are located, and the rate of search necessary to meet operational requirements. Because there is no "silver bullet," it is imperative that we turn our attention to using one or more technologies, together with advanced signal processing and ATR. In this realm, it would be ideal to establish as nearly an orthogonal set of technology measurements as possible so that high probabilities of detection can be maintained or improved while concomitantly reducing the false-alarm rate. Therefore, sensor fusion and ATR are a major factor in future increases in capability to be gained in mine detection as well as the proper selection of complementary technology sensors.

Finally, in attempting to determine an optimal set of technology thrust objectives for mine detection, it is also important to consider the inherent risks associated with the development of each technology. Some mine countermeasure techniques have been around for some time and the technologies have been well tested in the field. We may have reached the limits of their capabilities. Special approaches and new instrumental developments provide incentive for further investigation of some mature technologies. Other technologies are less mature, but they offer new possibilities for development. One way to evaluate the benefits of these different systems is by comparing the expected payoff against the anticipated risk. The payoff/risk chart is a method for articulating the joint assessment of risk and payoff. We now look at the different technology groups.

Technology Group 1: Standoff-Minefield Detection

The ability to detect and mark minefields prior to adverse encounter would be a major enabler for present or future fighting forces. Without an ability to see deeply, there will be no way for the Blue Force commander to avoid or be prepared for enemy obstacles—areas where the enemy wants to fight. Table 17.7-2 shows the relative maturity, research and development prospects, potential speed, general applicability, and mobility for technologies that are candidates for remote or standoff detection of minefields.

Table 17.7-2. Standoff Minefield Detection

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
GPR/SAR	R&D	High	Fast	All Weather	Moderate Size
IR	R&D	High	Fast	Most Weather	Small Size
Active IR	R&D	High	Fast	Most Weather	Moderate Size
Hyperspectral	R&D	High	Fast	Daytime Only	Moderate Size
Biotechnology	R&D	High	Slow	All Weather	Moderate Size

Figure 17.7-4 shows the payoff versus risk associated with passive IR, GPR/SAR, active IR polarization, hyperspectral detection, and the use of biotechnology agents to induce fluorescence in ground absorption of deteriorating mine explosives. All the technologies are rated high payoff because of the high military utility inherent using remote detection. The least mature of these technologies is the biotechnology approach, which is directed at developing enzymes auxotropic for TNT that will bioluminesce when exposed to this explosive. The highest performance to date has been with systems that distinguish the polarization differences between mines and ground reflections. This approach, however, is limited to detecting mines on the surface. Passive IR techniques have been demonstrated to detect buried mines, but the robustness of this approach appears to be limited to particular times during the diurnal cycle. Recent advances in SARs show promise for detecting metallic mines. Work performed at the University of Hawaii indicates the utility of using hyperspectral approaches in the 9-μm area to detect the large change in emissivity that occurs when the silicate in top soil is turned under during mine burial.
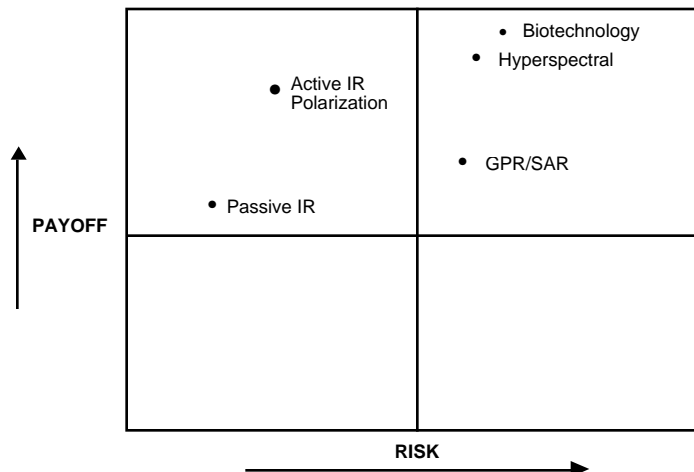

Figure 17.7-4. Standoff Minefield Detection

Technology Group 2: Vehicle-Mounted Mine Detection

There are also scenarios such as maintaining lines of communication for logistics forces in which close-in or near-field detection would be beneficial. Because road mines are generally used as part of an enemy ambush, a vehicle-mounted detector solves many of the problems of clearing roads. The Army is developing a vehicle-mounted mine detector for such scenarios. Table 17.7-3 shows the maturity, research and development prospects, potential speed, general applicability, and mobility for technologies that could be applied to vehicle-mounted detection.

Table 17.7-3. Vehicle-Mounted Mine Detection

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
Vapor	R&D	Good	Very Slow	Confirm Only	Small Size
Neutron Act.	R&D	Good	Slow	Confirm Only	Large Size
Biotechnology	Research	High	Slow	Primary Sensor	Moderate Size
GPR	R&D	High	Fast	Primary Sensor	Moderate Size
EMI	R&D	High	Fast	Primary Sensor	Small Size
Passive IR	R&D	Good	Fast	Primary Sensor	Small Size
Active IR	R&D	Good	Fast	Primary Sensor	Moderate Size
Acoustic	R&D	Good	Slow	Confirm Only	Large Size
Laser/Acoustic	R&D	High	Slow	Confirm Only	Large Size
Biosensors	R&D	Good	Fast	Primary Sensor	Small Size
Hyperspectral	R&D	Good	Fast	Primary Sensor	Small Size
NQR	R&D	High	Slow	Confirm Only	Moderate Size
Water Jet	R&D	Poor	Fast	Primary Sensor	Moderate Size

Because vehicle detection is generally an offshoot of handheld detection, there are many countries that have invested heavily in close-in mine detection. Canada, Germany, Japan, Russia, the UK, and the United States have significant developments across many mine-detection technologies. Many of these countries use sensor fusion and ATR to assist vehicle-mounted mine detectors. Most countries have significant capability for handheld detection of landmines.

Figure 17.7-5 shows the payoff versus risk in development for sensors to be used on vehicle platforms.
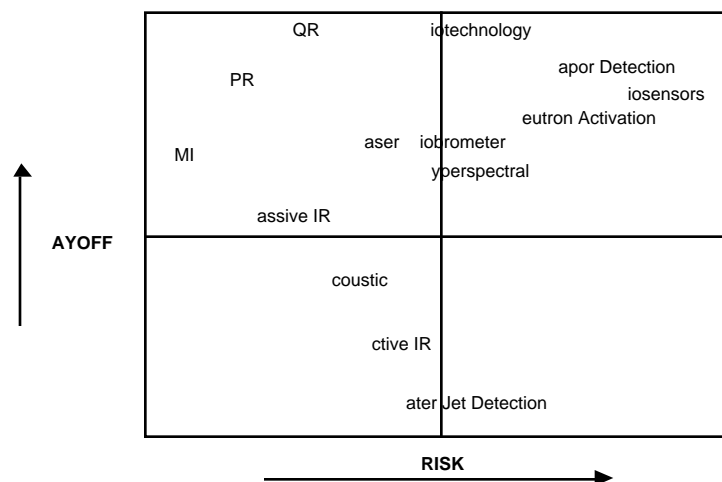

Figure 17.7-5. Vehicle-Mounted Mine Detection

The most familiar of these approaches is the EMI detector used to detect the presence of metallic objects. For vehicle-mounted detection of antitank mines, detection thresholds can be set relatively high, and good discrimination

between mines and clutter can be obtained along roads. To detect nonmetallic mines and mines with relatively small amounts of metal, it is necessary to use other detection technologies. Advances in GPRs have recently demonstrated high probabilities of detection with significantly fewer false alarms than earlier systems. Several systems have been developed and tested that incorporate passive IR detection, but in field tests the false alarms inherent in the IR approach limited its relative success. Future technologies that portend greater selectivity include neutron-activation techniques and vapor-particle detection.

Technology Group 3: Handheld Mine Detection

Handheld detectors are the time-honored approach for finding individual mines. Because most of the original antitank mines had metallic skins, most of the world's mine detectors look for metal, generally through EMI detection. Handheld operations are always slow and cannot be conducted in the presence of enemy fire. Recent peace-keeping roles of the United States place troops in areas after mines and booby traps have been deployed by opposing forces. The Army is developing a handheld standoff mine detection system (HSTAMIDS) to meet these requirements. Table 17.7-4 shows the maturity, research and development prospects, potential speed, general applicability, and mobility for technologies that could be applied to handheld detection.

Table 17.7-4. Handheld Detectors

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
Vapor Detection	R&D	Good	Slow	Confirm Only	Small Size
Biotechnology	R&D	High	Slow	Primary Sensor	Moderate Size
EMI	Fielded	High	Fast	Primary Sensor	Small Size
Passive IR	R&D	Good	Fast	Primary Sensor	Small Size
Biosensors	R&D	High	Fast	Primary Sensor	Small Size
NQR	R&D	High	Slow	Confirm Only	Moderate Size
GPR	R&D	High	Fast	Primary Sensor	Moderate Size
Photon Backscatter	R&D	High	Fast	Primary Sensor	Large Size

Figure 17.7-6 shows the relative payoffs and attendant risks of the different technologies with respect to the development and fielding of improved handheld detectors. EMI techniques are generally used by most the of the world's handheld-detector manufacturers. Recent research in EMI techniques has the potential to reduce false alarms through the use of the time constants associated with the rate of decay of the signal generated in the target material. Also, positive test results with GPR systems show promise for finding plastic and low-metallic mines. Emerging results from NQR experiments suggest that this technology could be used as a confirmation sensor.
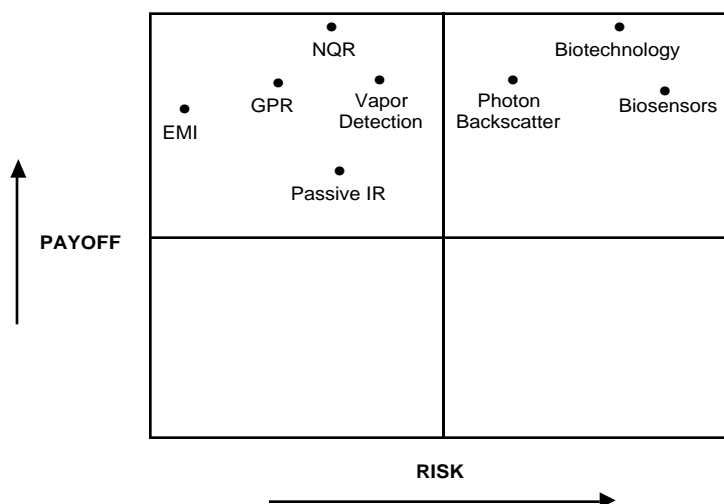

Figure 17.7-6. Handheld Detectors

2. *The Role of Speed of Neutralization*

The maneuver force is quickly placed at an extreme disadvantage when it has to extract itself from a minefield. The minefield is doctrinally covered by both direct and indirect fire. Waiting for breaching forces is not an option because the attacking force cannot continue the attack without breachers and will sustain unacceptable losses if it maintains its position within range of enemy direct and indirect fire. Ideally, a standoff neutralization system would complement the ability to remotely detect minefields. Standoff breachers can achieve surprise at the point of attack and permit maneuver forces to spend minimal time transiting the breached lane. Minimizing this transit time is important because it reduces maneuver forces' losses to direct and indirect fire while achieving surprise at the point of the breach.

Conceptually, there are several approaches to mine neutralization. For certain scenarios each conceptual approach holds some fundamental value.

Clearance. In its most simplistic sense, the approach would include manual removal of an individual mine from its location or detonation in situ of individual mines by sapper teams. This traditional engineer operation is tactically very slow, but produces safe lanes for following units. This approach is better suited to peacekeeping operations and is certainly not appropriate for maneuver warfare. Mechanized versions of mine clearance include plows and flails mounted on armored vehicles. The purpose of the plow or flail is to move the mines out of the path of the armored vehicle and subsequent vehicles. From a specific energy point of view, the plow and flail are probably the most efficient techniques to rapidly neutralize mines. From an operational point of view, these approaches are time consuming, and the armored vehicles used to propel these clearance devices are very vulnerable to direct and indirect fire.

Signature Duplication. The stimuli that activate mine fuzes can be duplicated to spoof the mines. Rollers mounted in front of armored vehicles produce a pressure signature similar to that of armored vehicles. Vehicle magnetic-signature duplicators (VEMASID) produce oscillating magnetic-flux densities that cause magnetic fuzes to prematurely actuate before the armored vehicle passes over the magnetic mine. These "spoofing" approaches work extremely well only against certain types of mines—those with simple pressure fuzes or single-axis magnetic fuzes. Some modern mines employ double-impulse fuzes (i.e., the fuze looks for the pressure pulse of the second or third roller wheel of an armored vehicle) or multiple-sensor fuzes. For multiple-sensor mine fuzes, it is important that the clearing system contain a spectrum of "spoofing capabilities"—acoustic, seismic, pressure, and magnetic.

Blast Effect Reduction. In this approach, the vehicle and its associated mine-detection and mine-neutralization items are designed to withstand the blast output of the landmines. Several South African vehicles employ a v-shaped chassis designed to deflect the mine blast wave from the vehicle. In addition, these vehicles employ shielding for shrapnel in the form of specially designed seats to dissipate blast loads before they are imparted to the passengers. The approach is successful in areas where the mine threat does not include shape charge or explosively formed fragments as mine warheads.

Directed Energy. There are several directed-energy approaches that can be used for mine neutralization.

Lasers. Successful explosive ordnance disposal lasers have been built and tested on armored vehicles to clear airfield runways. A 5- to 10-sec laser pulse causes fracture/opening of the ordnance case. Further application of the laser energy can induce low-order deflagrations or burning of the explosive components. Because the laser energy is absorbed in the first micrometer of the explosive material, it is not clear that current lasers can deposit sufficient energy in the secondary explosives to cause detonation. When the mines or ordnance is buried, the narrow energy absorption in the first micrometer of solid requires that the laser spend enough time and energy to vaporize the dirt between the laser and the mine/ordnance casing. Clearly, the extraordinary times and energy required to vaporize soil prohibit the use of laser for neutralization of buried mines and ordnance.

High-Power Microwaves. High-power microwaves (HPM) can be used to attack the electronic/electric components of mine fuzes. The most obvious way is to induce sufficient current in the bridge-wire detonator to cause detonation. Generally, even in open air tests, this approach requires 100 W/cm^2 to induce detonation. Usually, the fuze is protected within the mine structure, making it more difficult to produce this high-energy density at the bridgewire. Other neutralization approaches include component burn-out, spoofing, and mine electronic jamming. To

accomplish these objectives, particularly with metallic mines, requires high-power systems to achieve even modest fields within the mine structure. In addition, each metallic mine will produce varying degrees of shielding at different frequencies. The tighter the production standard of the mine, the larger the source required to achieve useful levels within the mine. Attacking buried mines restricts the frequencies that can be used. Soils that contain significant amounts of water also restrict the robustness of the HPM approach. On the other hand, the HPM, unlike lasers, does not have to burn its way to the mine fuze to induce spoofing, jamming, or burnout. In addition, the HPM can produce significant fields over several square meters. This gives the HPM a large footprint that ultimately can provide moderate neutralization speeds for the host vehicle.

Charged Particle Beams. Charged particle beams (CPBs) such as electron beams are strongly scattered in air, particularly at the lower energies. The charged particles are said to have a "range" in air before they lose 1/e of their initial energy. As the accelerating voltage used to produce these beams is increased, the range of the electrons in air increases substantially. Recent advances in bringing million electron-volt pulses into air show promise for propagation distances approaching a kilometer. Just as the charged particle beams have a range in air, they also have a range in soil and a range in various mine components. Electron beams have been shown to induce detonations in both primary and secondary explosives. In theory, it is possible to design a system based on known energy losses in air, soil, and mine components that will detonate the main charge explosive in landmines. The difficulties found in adopting charged particle beams into military systems are numerous: developing an accelerator that would fit any current land vehicle; providing radiation protection during use; and sustainability of a complex accelerator in a dirty battlefield. Like the laser, the charged-particle beam has an extremely narrow footprint. Rastering the beam to provide blind protection across the vehicle front would slow the vehicle to speeds already obtainable with full-width plows. To truly be useful, the charged-particle beam would need to be tied to a forward-looking mine detector. Although advancements are being made in forward-looking detectors (FLIR and UWB), significant progress must be made in raising the probabilities of detection before a hunter/killer concept using a particle beam could be effective.

Explosive Neutralization. Traditionally, explosive line charges and fuel-air explosive devices have been used to clear minefields. This approach is effective against simple, single-impulse mine fuzes; however, there are many single-impulse fuzes that have been fielded that have been modified to require long impulses before fuze actuation occurs. Pressure bladders with different size holes are used to produce impulse-sensitive mines that cannot be actuated by line charges or fuel-air explosives. Other simple pressure systems have been modified so that there is very little surface area that is perpendicular to line charge blast waves. Developments in the United States with explosive powders and in Canada with ladder charges have shown that the main explosive charge in surface land mines can be sympathetically detonated. As the mines are buried deeper and deeper, the efficacy of these approaches degenerates into structural damage to the landmines. But because it can be anticipated that in a mobile war more than 80 percent of the mines would be scattered on the surface, these explosive approaches are attractive. A system approach that incorporated a track-width mine plow, a VEMASID, and an "explosive powder line charge" would be effective against all types of mines.

Shaped-Charge Neutralization. Landmine main charge explosives are susceptible to detonation induced by shaped charges. Even though TNT, a very insensitive explosive, is used by many nations as a landmine main charge explosive, it too is vulnerable to high-velocity shaped charges. The shaped charges are tied together with primacord in a large lattice net that can be rocket propelled over a minefield. The detonation of this explosive net of shaped charges rapidly clears a breach path through a minefield.

Standoff minefield neutralization requires a technology capable of causing mine to actuate at large standoff distances or the development of a system that can be remotely placed into the minefield to clear a breach lane. To be truly effective, the approach must also contain the element of surprise. Approaches that slowly and methodologically clear or neutralize individual mines will be quickly reduced by enemy direct and indirect fire and will also alert the enemy to the planned lane of breach.

Figures 17.7-7 and 17.7-8 show the probability of surface mine neutralization and the probability of buried (4–10 in.) mine neutralization, respectively, as a function of speed of neutralization.
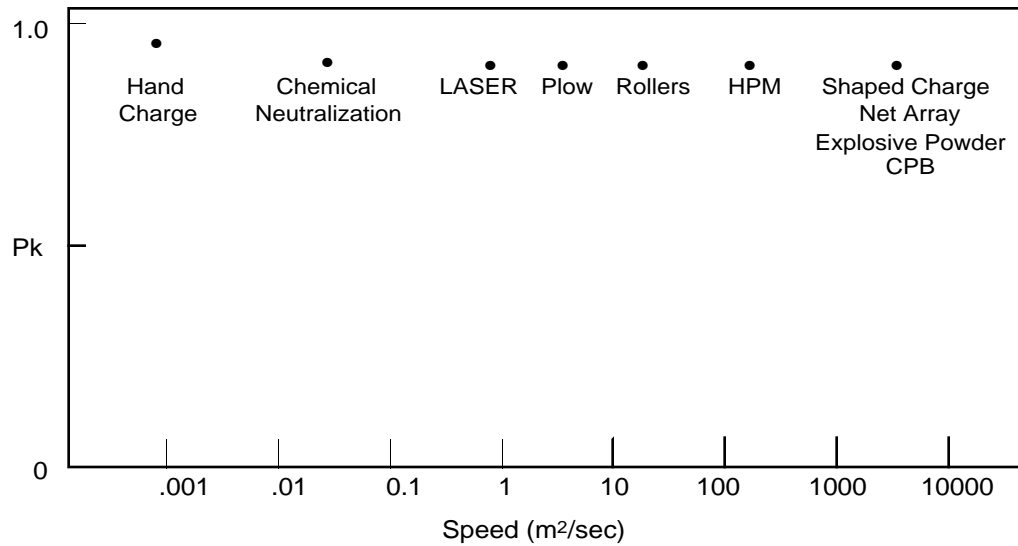
1.0

Hand
Charge

Chemical
Neutralization

LASER Plow Rollers HPM

Shaped Charge
Net Array
Explosive Powder
CPB

Pk

0

.001   .01   0.1   1   10   100   1000   10000

Speed (m²/sec)

Figure 17.7-7. Area Neutralization Speed for Surface

1.0

Hand
Charge

Chemical
Neutralization

Plow   Rollers
HPM

Shaped Charge
Net Array

Pk

0.5

0

.001   .01   0.1   1   10   100   1000   10000
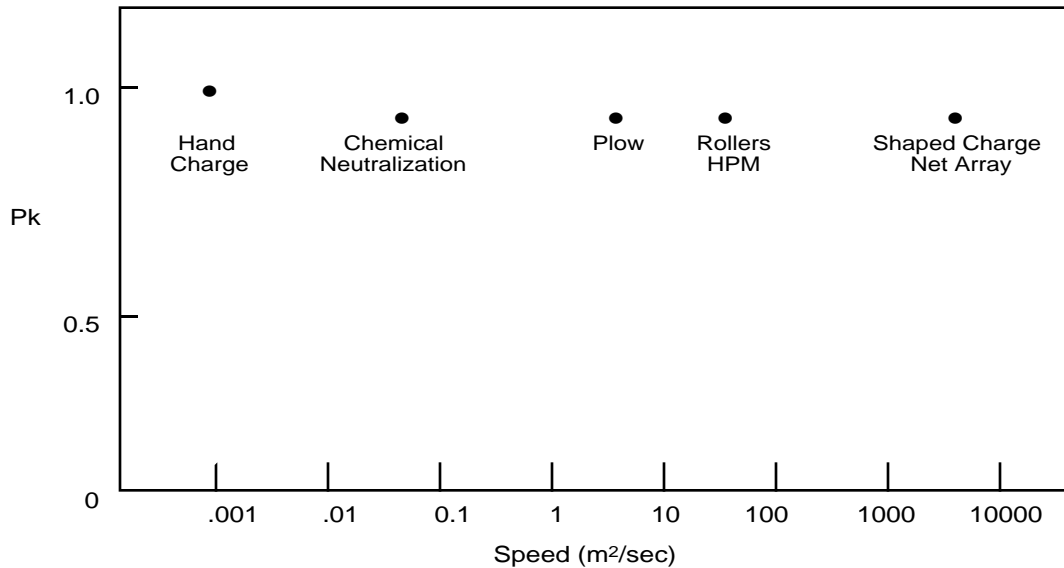
Speed (m²/sec)

Figure 17.7-8. Area Neutralization Speed for Buried Mines

There are major differences in technology capabilities for surface and buried landmines. As discussed previously, lasers have demonstrated utility for neutralizing surface mines and ordnance and have no capability against buried munitions. The HPM approach will work in dry soils and sands to moderate depths against electronic mines. Electron beams will only become attractive when they can be combined with forward-looking detectors that have a high probability of detection.

Advanced explosive systems must be combined with plows for full-spectrum mine clearance because explosive shock pressures dissipate too quickly in air and soil. One approach that does maintain the ability to detonate buried land mines is a shaped charge. The diameter and speed of the shaped charge determine the explosive actuation depths. Explosive net systems that place shaped charges at the lattice intersections of net arrays can achieve rapid neutralization times over large footprints.

There are operational scenarios that make good use of most of the preceding technologies. Table 17.7-5 shows the increase in capability for the different technology concepts.

Table 17.7-5. Mine Neutralization Technologies

	Increase in Selectivity →				
Technology	**Surface Mines**	**Buried Mines**	**Attacks Fuzes**	**Attacks Main Charge**	**High Tempo Ops**
Hand Clearance	Yes	Yes	No	No	No
Roller	Yes	Yes	Yes	No	Yes
Flail	Yes	Yes	Yes	Yes	No
Plow	Yes	Yes	No	Yes	Yes
VEMASID	Yes	Yes	Yes	No	Yes
Chemical Neutralization	Yes	Yes	No	Yes	No
Laser	Yes	No	No	No	No
HPM	Yes	Sometimes	Yes	No	Yes
CPB	Yes	Yes	Yes	Yes	
Explosive Ladder Charge	Yes	Sometimes	Yes	Yes	Yes
Explosive Powder Line Charge	Yes	No	Yes	Yes	Yes
Shaped Charge Net Array	Yes	Yes	Yes	Yes	Yes

To better understand how these technologies can be used in different mine warfare scenarios, we now investigate the applicability of these technologies to the following technology groups.

Technology Group 4: Standoff Minefield Neutralization

Table 17.7-6 shows the maturity, R&D prospects, applicability, and mobility associated with different technologies that are appropriate for standoff minefield neutralization.

Table 17.7-6. Standoff Minefield Neutralization

Technology	**Maturity**	**R&D Prospects**	**Applicability**	**Mobility**
MICLIC	Fielded	Poor	Slow	High
SLUFAE	Type Classified	Poor	Slow	High
Explosive Ladder	Development	Good	Fast	Good
Explosive Powder Line Charge	R&D	Good	Fast	High
Shaped Charge Array	Development	High	Fast	High

The fielded mine-clearing line charge (MICLIC) is towed in a trailer by an armored vehicle. The MICLIC is effective only against simple pressure plate fuzed mines. The surface-launched fuel air explosive (SLUFAE) is likewise limited in its effectiveness to simple pressure plate mines, but this system has its own dedicated vehicle to insure mobility. The explosive ladder is rocket propelled over a minefield and uses large amounts of high explosive to destroy but not necessarily detonate all mines in or under the ladder charge. The explosive powder line charge disperses explosive powders once the line charge strikes the earth. The high pressures and impulses imparted by detonating the explosive charge cause sympathetic detonation of all mine main charges of surface mines. The shaped-charge array is also propelled as an expanding net over the minefield. The net consists of primacord tied to shaped

charges placed in a lattice array. The shaped charges induce detonation of all mines under the net. The shaped charge array net is about to enter engineering and manufacturing development.

The payoff versus the risks of development are shown in Figure 17.7-9 for different standoff-minefield-neutralization technologies. The technologies offering the highest payoff are those that attack the mine main explosive charge.
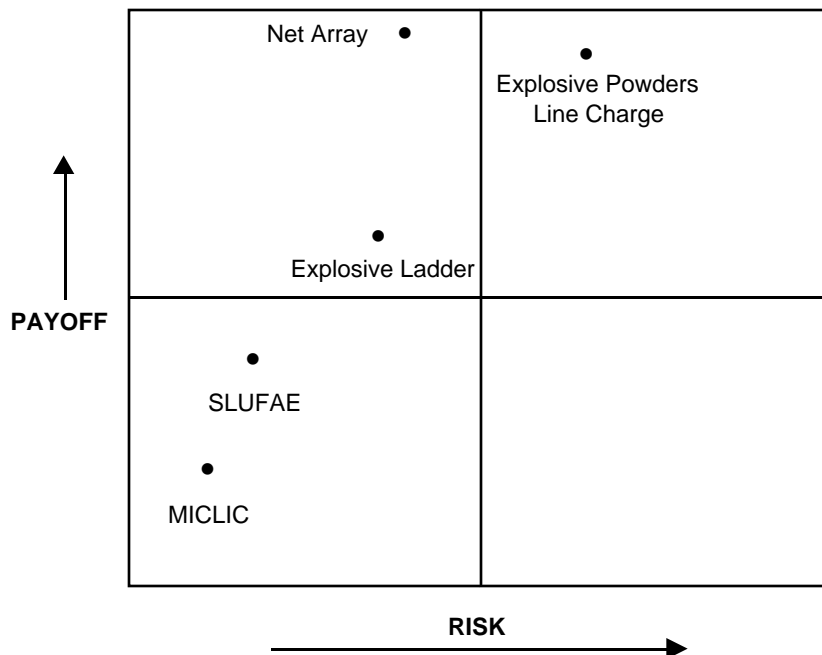

Figure 17.7-9. Standoff Minefield Neutralization

Technology Group 5: Vehicle-Mounted Mine Neutralization

There are many roles in which vehicle-mounted mine neutralization systems are used. For combat operations, vehicle-mounted neutralization systems are used to provide organic neutralization capability to the lead breaching vehicle, although standoff minefield neutralization systems may have cleared the breach. Additional combat operations include proofing of cleared lanes and mined areas and maintaining open combat roads and trails. After combat operations, vehicle-mounted mine neutralizers are used to clear mined areas and to proof areas where mines have been detected and destroyed or removed. Table 17.7-7 lists the properties of various approaches to mounting neutralization systems on vehicle platforms.

The preferred technology approaches are those that are effective against all types of mines and can be used to create rapid breaches under fire. Rollers are limited to attacking simple pressure-plate mines and some types of magnetic-fuzed mines. Track-width plows can create lanes at the rate of 7–10 kph, but full-width plows travel at significantly lower speeds. Flails are best used in rear areas because of their very slow rate of clearance. Vehicle magnetic signature duplicators (VEMASID) only attack magnetic mine fuzes and can be used together with mine plows or rollers to enable fast breaching. Directed-energy approaches have applications at the present time limited to attacking electronic fuzes or mines on the surface.

Figure 17.7-10 portrays the relative payoffs of different vehicle mounted mine neutralization technologies with increasing risk. The fielded items (i.e., roller, VEMASID, flail, and plow) are the lowest risk systems. The reason for increased payoff of the flail and plow over the VEMASID and roller is the ability of the flail and plow to neutralize all type of mines, irrespective of how they may be fuzed.

Table 17.7-7. Vehicle-Mounted Mine Neutralization

| Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
Roller	Fielded		< 10 kph	Pressure/Tilt Rod	On/Off road
Plow	Fielded		< 5 kph	All mine types	Off road
Flail	Fielded		< 2 kph	All mine types	No Combat Breach
VEMASID	Type Classified		< 30 kph	Magnetic	On/Off road
Chemical Neutron	R&D	Good	< 2 kph	All mine types	On/Off road
Laser	R&D	Good	< 2 kph	Surface mines	On/Off road
HPM	R&D	High	< 10 kph	Electronic mines	On/Off road
CPB	R&D	Good	< 5 kph	All mine types	On/Off road
Small Shaped Charged	R&D	High	< 30 kph	All mine types	Off road
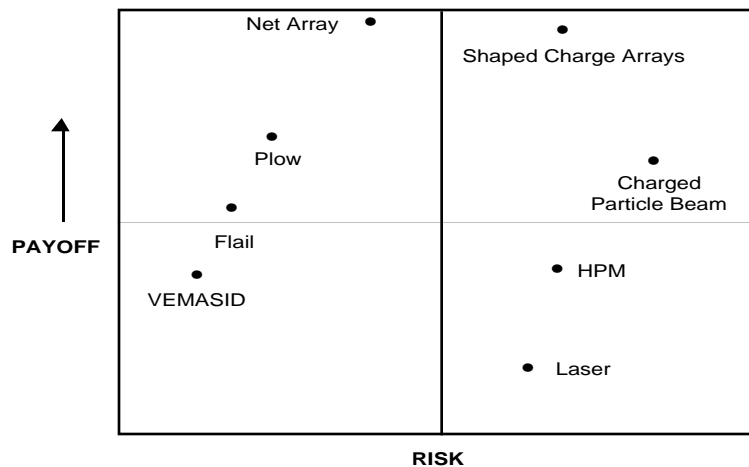
Figure 17.7-10. Vehicle-Mounted Neutralization

The plow has more risk than other fielded systems because the current plows are track-width clearance devices. Additional risk is incurred as full-width plows are being developed. Generally, the directed-energy approaches are riskier than the current mechanical and electrical fielded systems, with little additional payoff anticipated. Explosive net arrays, however, portend large leaps ahead in system capability and mobility.

Technology Group 6: Man-Portable Neutralizers

When mines are detected or found during road marches or road clearance operations, combat engineers carefully located and mark the mine. A decision is made to blow the mine in place, have an explosive ordnance disposal (EOD) expert remove the device, or to drive around the marked mine. For dismounted infantry assault breach situations, the infantry may face a combination of antipersonnel landmines, antitank mines, barbed wire, and booby traps. For the infantry to breach this complex obstacle, the only technologies currently known that can rapidly create a breached lane through the minefield are explosive line charges and explosive line charges with grenades placed at

different intervals. The combination of explosive line charges with grenades helps to clear barbed wire while creating a narrow foot path. For noncombat situations, there are mine suits, special boots, helmets, and visors to protect soldiers performing mine clearance. These operations are dangerous and avoided wherever possible. Dismounted detection and neutralization of mines in rear areas are undertaken only in special circumstances where the mines are an imminent danger to present or anticipated operations.

WORLDWIDE TECHNOLOGY ASSESSMENT

With the recent worldwide visibility of the landmine problem, many nations have taken a new interest in developing new close-in mine-detection and mine-neutralization technologies. New programs to test and evaluate mine-detection equipment have been established at ISPRA, Italy, and in Canada. The establishment in the United States of the Joint Unexploded Ordnance Coordination Office (JUXOCO) under OSD leadership also points the way toward benchmarked progress to understand and solve the mine detection problem. These efforts will primarily address technology approaches that are not time sensitive.

In the countermine area specifically, there are several historical leaders in the development of mine-detection and mine-neutralization equipment: France, Germany, UK, Israel, South Africa, Russia, and the United States. Germany continues to be a leader in EMI hand-held detectors with Forster and Vallon. Dornier has developed standoff minefield-detection sensors together with Carl Zeiss and ATR algorithms by the Fraunhofer Institute. Elta of Israel has developed a GPR for use on remotely controlled ground vehicles. Both Israel and Russia have been leaders in developing advanced mechanical and spoofing technologies to be mounted on ground platforms. South Africa has developed new methods of using multiple canines for mine detection and for providing blast protection for countermine vehicles. Canada and the UK have recently invested heavily in humanitarian demining detection technologies and systems.

In the United States, Tracor (more recently purchased by Marconi) has been a leading developer of handheld and vehicle detectors as well as the developer of explosive arrays using shaped charges to neutralize mines. Coleman Research has developed both handheld and vehicle-mounted mine-detection systems employing EMI, GPR, and IR. EGG and GeoCenters developed vehicle-mounted mine-detection systems that also used these technologies. SAIC has developed vehicle-mounted thermal neutron approaches to detect buried nitrogen and nitrogen compounds. Sandia National Laboratory has developed X-ray backscatter techniques for image identification of mines.

The technology assessments for each country are broken out two different ways in the following pages:

- The first method assesses each country's capability in different technology groups: minefield detection, vehicle-mounted detection, handheld detection, standoff minefield neutralization, vehicle-mounted neutralization, and man-portable neutralization. These technology group assessments generally include several technologies in each operational area being undertaken by an individual country.

- The second method addresses each specific technology and offers a separate assessment by country.

This approach provides insight into both the operational investments and technology investments of each country.

Figure 17.7-11. Mine-Detection Systems WTA Summary

Country	Minefield Detection	Vehicle-Mounted Detection	Handheld Detection
Australia	●	●●	●●●●
Bulgaria		●	●●
Canada	●●●	●●●●	●●●●
China	●	●●	●●
Czech Republic	●	●	●●
Denmark	●	●	●●
Egypt			●●●
Finland	●	●	●●
France	●●	●●●	●●●
Germany	●●●	●●●	●●●●
Hungary			●●
India		●	●
Iran			●
Iraq		●	●●
Israel	●●	●●●●	●●
Italy			●●
Japan		●	
Libya			●
Netherlands	●●●	●●	●●●
North Korea			●●
Norway			●●
Pakistan		●	●●
Poland			●●
Russia	●●	●●●	
Slovak Republic			●●
South Africa	●●	●●●●	●●●●
South Korea		●	●●
Spain			●●
Sweden			●●
Switzerland			●●
Syria		●	●●
UK	●●	●●●	●●●
United States	●●●	●●●●	●●●●
Vietnam		●	●●

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

(Continued)

Country	Standoff Neutralization	Vehicle-Mounted Neutralization	Man-Portable Neutralization
Australia	●	●●	●●●
Bulgaria		●●	●●
Canada	●●●●	●●●	●●●
China	●●	●●●●	●●
Czech Republic		●●	●●
Denmark		●●	●●
Egypt		●●	●●
Finland		●●	●●
France	●●	●●●●	●●●
Germany	●●	●●●●	●●●●
Hungary		●●	●●
India		●●	●●
Iran		●	●
Iraq		●●●	●●
Israel	●●●	●●●●	●●●●
Italy		●●	●●
Japan		●	●
Libya			
Netherlands	●●	●●	●●
North Korea		●	●●
Norway		●	●●
Pakistan		●	●
Poland		●●	●●
Russia	●●●●	●●●●	●●●●
Slovak Republic		●	●●
South Africa	●●	●●●●	●●●●
South Korea		●	●
Spain		●	●
Sweden		●	●●
Switzerland		●	●
Syria		●	●
UK	●●●●	●●●●	●●●●
United States	●●●●	●●●●	●●●●
Vietnam		●	●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●
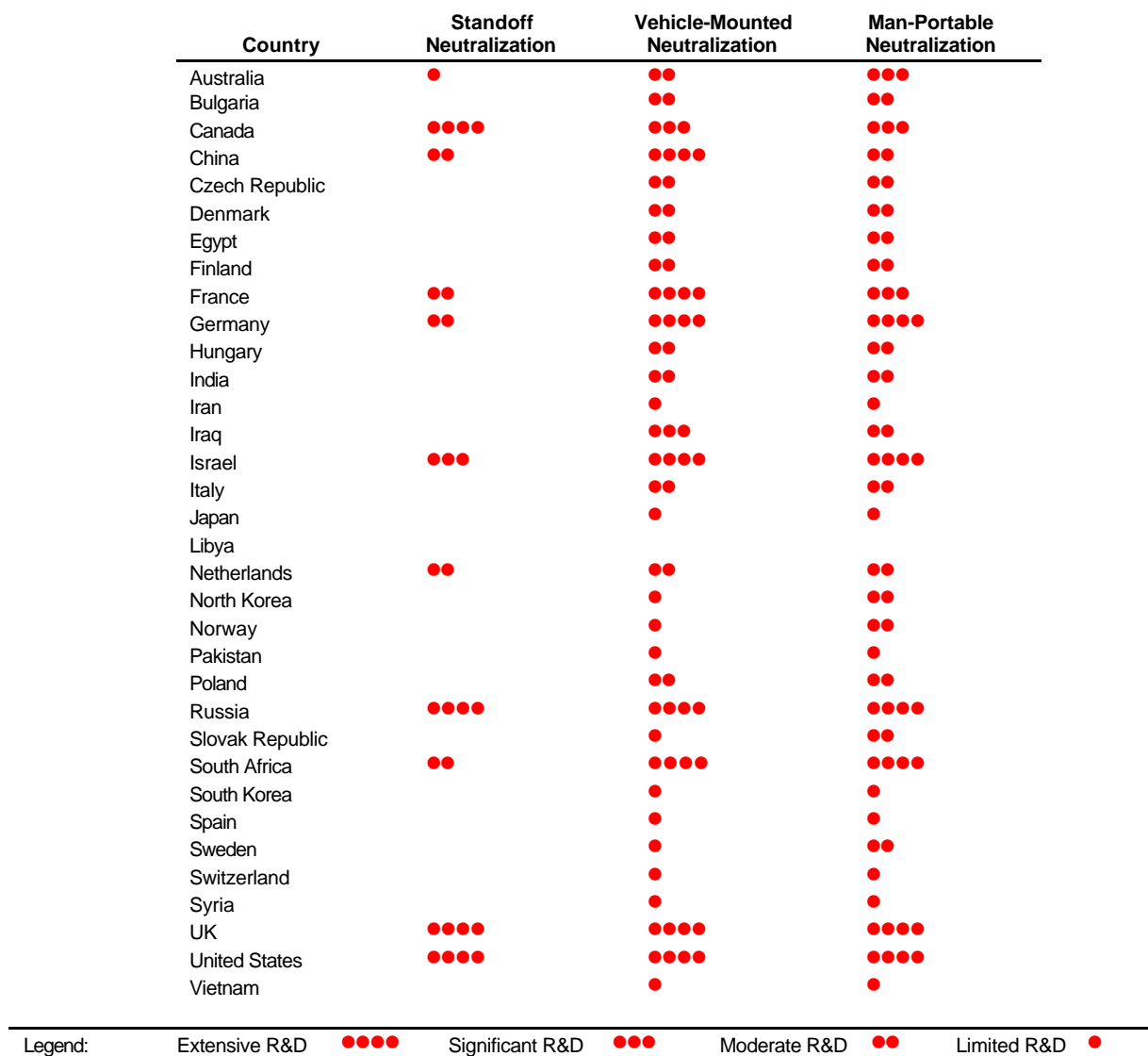
Figure 17.7-11. Mine Detection Systems WTA Summary (Cont'd)

LIST OF TECHNOLOGY DATASHEETS
III-17.7. LAND MINE COUNTERMEASURES

DATA SHEET III-17.7. ACOUSTIC DETECTION

Developing Critical Technology Parameter	Synthetic aperture acoustic sensor arrays are used to detect scattering of Raleigh waves by buried objects such as mines. Early results show promise for detecting anti-tank mines to distances of 10 m. Target cross sections were roughly two to three times actual size in first measurements. Raleigh wave transmission through inhomogeneous variously compacted soils leads to ambiguities in target position and target recognition. Smaller sensors placed in larger arrays will improve both detection and recognition of mine targets in the next 5 years.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Discrimination of landmines from wood, rocks, or other clutter sources will be the principal issue in developing this type of detector. Since there is no specific information about the interior of the mine returning in the sound reflected from the mine, there is no a priori reason to expect that other reflecting will not appear the same as mines. The technique does have the advantage of detecting from a standoff distance and permits the fusion of the output of other sensors prior to target identification.
Major Commercial Applications	Acoustic synthetic aperture arrays can also be used for detection and removal of unexploded ordnance or other environmental contaminants.
Affordability	Development of robust software to manage relatively inexpensive acoustic arrays will be the principal cost driver.

RATIONALE

Synthetic arrays can be used to detect scattering of Raleigh waves traveling near Earth's surface. This technology could be used to cue either GPRs or EMI detectors to detect buried objects. The ability to see ahead and cue other sensors to probable target locations is a major advantage of this technology approach.

This technology would best be suited to vehicle-mounted detectors that address the ground standoff mine-detection (GSTAMIDS) operational requirements document (ORD). The technology approach could serve as a block upgrade to the current science and technology (S&T) program Mine Hunter/killer.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●	Japan	●●	UK	●●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Japan, Germany, the UK, and the United States are currently performing research and development in acoustic techniques for use with hand-held detectors. Because hand-held detectors are small, the acoustic detection techniques used generally involve an acoustic source and a laser vibrometer for target detection (see also laser vibrometer technology section). Advanced wide-area mines developed by Germany, the UK, and the United States utilize Rayleigh wave scattering for vehicle acquisition and targeting, so it is likely that these same countries could incorporate this technology on vehicle-mounted detectors.

DATA SHEET III-17.7. AIR-CHISEL CLEARANCE/NEUTRALIZATION

Developing Critical Technology Parameter	Once a mine detector has indicated the probable location of a mine, dismounted infantry usually approach the indicated spot in a prone position and use a hand probe carefully to try to find the suspected mine. Air chisels are a mechanized method to rapidly uncover soil, leaves, and other debris from the suspected mine location. Air chisels placed on remote-controlled detection platforms could be used to quickly uncover soil and debris from suspected mine locations.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	The principal issue is the ability of air chisels to rapidly clear hard and dried soils without causing mine actuation.
Major Commercial Applications	This approach could also be used for humanitarian demining operations.
Affordability	This approach uses commercial air-compressor technology and would be another tool for quickly finding and identifying buried land mines.

RATIONALE

Once potential mines have been identified with electronic detectors, air chisels are an inexpensive and effective method to rapidly remove soil down to and around the mine. This approach is applicable only to the ever-increasing role that peacekeeping operations now play in the deployment of U.S. armed forces.

WORLDWIDE TECHNOLOGY ASSESSMENT

Finland	●●●●	Germany	●●●●	India	●●●●	Italy	●●●●
Japan	●●●●	Norway	●●●●	Pakistan	●●●●	South Africa	●●●●
Spain	●●●●	Sweden	●●●●	UK	●●●●	United States	●●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

This technology is the result of humanitarian demining interest in finding relatively mature and cost-effective technologies to detect and find antipersonnel mines. Backpack pressurized cylinders can serve as a high-pressure air source for use in a man-portable detector.

Air compressors, as well as fittings to produce high stagnation pressures through small orifices, are commercially available throughout the world. Air compressors could be vehicle mounted and used for both mounted and dismounted operations.

Air chisels would be most beneficial in areas with substantial leaf coverage or in relatively soft soils and sand.

DATA SHEET III-17.7. HYPERSPECTRAL DETECTION

Developing Critical Technology Parameter	By looking at very narrow segments of the optical spectrum it is possible to detect natural artifacts commensurate with the placement or burial of a mine. Natural vegetation can exhibit changes in chlorophyll due to the presence of a mine. Other anomalies include the difference in emissivity of silicate in soil at 9 µm. When soil is overturned, there is less silicate at the surface, and the silicate that is at the surface may be obscured by the overturned dirt. The anomaly is detectable sometimes for periods of weeks until the effects of wind and rain return that section to its natural state. The point is that selective absorption or reflection at very narrow frequency bands provide valuable clues as to the presence of man-made objects.
Critical Materials	High-resolution FPAs are needed to obtain high-resolution images of small objects such as mines that may be at the surface or buried. The higher the detection platform is to be flown, the larger the FPA needed to cover meaningful areas on the ground.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Special algorithms must be developed to identify individual mines and minefields.
Technical Issues	Overturned soil causes large change in emissivity of soil at 9 µm when silicate is present in soils. Effect diminishes with times and with rain.
Major Commercial Applications	Potential use in evaluating environmentally impacted areas or areas where large amounts of UXO exist.
Affordability	Requires expensive airborne optronic systems and software.

RATIONALE

Remote minefield detection is at the heart of maneuver warfare. Detection of minefields before adverse encounter requires technologies employed from airborne platforms. Hyperspectral detection can be accomplished in small UAVs and can be used to complement IR or SAR data gathered from the same or other platforms.

Maintaining logistic chains along roads and combat trails requires daily use of mine-detection equipment. Freshly dug holes for mines can be detected by large changes in emissivity at 9 µm. Detection of these daily changes could vastly improve present mechanical clearing methods.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

European community investment in humanitarian demining technologies has resulted in the investigation of technologies for the wide-area detection of mines. Belgium has developed visible and infrared hyperspectral and multispectral approaches for the detection of existent large minefields. Although hyperspectral technology is widely available throughout the world in the visible portion of the spectrum, system costs are driven by the aerial platform needed to cover large land areas. Germany and the United States have invested in using this technology for standoff minefield detection systems.

DATA SHEET III-17.7. BIOTECHNOLOGY DETECTION

Developing Critical Technology Parameter	Development of enzymes that are auxotropic for TNT and luminescent when they react with TNT. These enzymes can be used to find buried mines and UXO that leak trace amounts of explosives into the environment.
Critical Materials	Because there are no known natural enzymes that are auxotropic for TNT and luminescent when exposed to TNT, new enzymes will have to be identified.
Unique Test, Production, Inspection Equipment	Test programs must be developed to insure that the enzymes are compatible and non-incursive on the environment.
Unique Software	None identified.
Technical Issues	The amount of TNT/explosive residue on plants and vegetation from mines buried in the ground is not known and will be a key to how many enzymes will be required to cover suspected mine areas.
Major Commercial Applications	This technique could be used for environmental cleanup and UXO remediation of military sites.
Affordability	Potentially an inexpensive means to interrogate large land areas to determine the presence of mines and minefields.

RATIONALE

Enzymes can be spread over suspected mined areas and the specific reaction with the mine main explosive charge explosives can be monitored from UAVs. The approach may require many hours between enzyme application and detectable bioluminescence. Alternatively, dismounted soldiers could be used to interrogate specific areas after the enzymes have been emplaced. Both approaches are in line with the current standoff minefield detection ORD to rapidly detect mines and minefields.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

The U.S. Department of Energy is developing this novel approach that builds on expertise at Savannah River to detect trace residues of chemicals and other potentially hazardous materials in the environment.

DATA SHEET III-17.7. DIRECTED-ENERGY NEUTRALIZATION

Developing Critical Technology Parameter	HPMs can be directed at mines employing electronic fuzes to burn out electronic components, ignite the bridgewire fuze, upset electronic functioning, or spoof the fuze into interpreting the microwave signal as a proper firing signal. High-power electron beams can be brought into the atmosphere to attack surface and buried mines. The energy deposit initiates detonation in the mine main charge explosive.
Critical Materials	While laboratory HPM and electron beam sources exist, they are one-of-a-kind items. Special klystron and electron-beam assemblies must be designed for field applications.
Unique Test, Production, Inspection Equipment	Development of radiation-hardened test equipment to test high-power output.
Unique Software	None identified.
Technical Issues	Robustness of approach that either upsets or spoofs mine electronic firing algorithm is a critical issue for HPM applications because it attacks the fuze. Determining both the total energy deposition and the rate of energy deposition within the mine main explosive charge will be crucial to establish the efficacy of the electron-beam neutralization approach, particularly against explosives such as TNT.
Major Commercial Applications	HPM devices can be used to combat terrorists or subversive groups that rely on electronic devices or communication.
Affordability	Directed-energy approaches are large and expensive.

RATIONALE

Modern mines use electronic fuzing tied to one or more sensors for target acquisition. Many mines also employ electronic self-destruct mechanisms. These electronic circuits are vulnerable to directed-energy weapons such as HPM or charged particle beams. Employed from a standoff distance, these devices would meet the requirements for the standoff neutralization ORD.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●	Russia	●●	UK	●	United States	●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The former Soviet Union made large investments in HPM technology and since its dissolution, Russia has marketed HPM technology to neutralize antipersonnel land mines for humanitarian demining. France, Germany, the UK, and the United States have all investigated the use of HPMs for mine neutralization with varying degrees of success. HPMs are most effective against electronic mine fuzes that are not protected, that is, the electronics are not surrounded by a Faraday cage. Success in neutralizing mines incorporating bridge-wire fuzes require high power density levels at the target to initiate land mines.

DATA SHEET III-17.7. EMI DETECTOR

Developing Critical Technology Parameter	New fast-response EMI detectors that use both real and quadrature data to determine the time constant rate of decay of mine targets have been developed. These new data provide the opportunity to both detect and classify mine targets. This additional information also provides a basis for rejection of clutter, which will result in fewer false alarms. This new powerful technique may also be able to detect the void produced by plastic mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Special coils must be developed that can both transmit and detect time constants on the order of 1 μsec or less. The time constants associated with different soils and their attendant moisture must also be measured and appropriately archived.
Unique Software	New software must be developed to accurately and quickly evaluate these microsecond interrogations.
Technical Issues	Development of physics-based models to help identify and separate mine and clutter objects is necessary, particularly in forming a rational basis to reject the even larger amounts of clutter associated with interrogating this larger spectrum. The use of these detectors in wet soil against small mines is also problematic.
Major Commercial Applications	Coin relic hunting detectors or commercial detectors to detect metal pipes in the ground or behind walls.
Affordability	Technology is relatively inexpensive and straightforward.

RATIONALE

EMI detectors are the most ubiquitous mine- and relic-hunting detectors. High thresholds can be used to distinguish large metallic landmines. Large amounts of metallic clutter on the battlefield lead to extremely high false-alarm rates when EMI detectors are used to find small antipersonnel landmines. New detection capabilities subtend the ability to better distinguish mines from clutter.

This approach is consistent with the HSTAMIDS and the ground standoff mine detection system (GSTAMIDS). The new EMI techniques, when used with GPR techniques, may provide keys to providing substantive improvement in both handheld and vehicle-mounted mine detectors.

WORLDWIDE TECHNOLOGY ASSESSMENT

Austria	●●●●	Bulgaria	●	Canada	●●	China	●
Denmark	●●	Egypt	●	Finland	●	Germany	●●●●
India	●	Italy	●	Japan	●●	Pakistan	●
South Africa	●●	Spain	●	Sweden	●	UK	●●●
United States	●●●●						

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The high interest in humanitarian demining has lead to renewed interest and investment in EMI detectors throughout the world. A new Australian EMI approach for military mine detectors has spurred interest in the use of EMI detectors against low-metal content antipersonnel landmines. Austria, Germany, France, and the UK also make high-performance mine detectors. The NATO nations are now investigating the fusion of GPR technology with EMI threshold techniques for use as detectors of both metallic and plastic mines.

Emerging research currently being conducted by multi-university research initiatives through the Army Research Office has demonstrated marked improvements in the rejection of false alarms using time-domain and frequency-domain EMI techniques. Both of these techniques are being combined with advanced signal-processing techniques to produce ROC curves that evidence major growth in the reduction of false alarms.

DATA SHEET III-17.7. EMULATED BIOLOGICAL SENSORS

Developing Critical Technology Parameter	Sensor response to a wide range of explosive compounds with small vapor pressures is difficult to measure in the laboratory. Performing these measurments in nitroaromatic backgrounds that can vary over more than four orders of magnitude adds greater complexity. The design and synthesis of complementary chemoselective coatings for nitroaromatics is coupled with the use surface acoustic wave (SAW) devices to determine explosive vapor sorption and selectivity.
Critical Materials	The construction of carbon bolometers to perform reproducible detection of explosive compounds may be difficult to convert from the laboratory to production status.
Unique Test, Production, Inspection Equipment	The performance of these sensors in areas already contaminated with explosive materials is currently not known.
Unique Software	None identified.
Technical Issues	The ability to locate mines in environments with high explosive vapor or high explosive residue areas is needed for robust performance in field applications. The sensitivity of these devices in high backgrounds of the explosive to be detected is not currently documented.
Major Commercial Applications	These devices could be used as explosive detectors for airports and for building security.
Affordability	The technology will be moderately expensive to develop and relatively inexpensive to produce in quantity.

RATIONALE

Emulation of "dog's nose" will provide detection and discrimination of combinations of many different trace chemical vapors.

Systems must reliably detect a wide range of explosive compounds and accurately locate landmines with explosive fills ranging from 1 ounce to more than 20 lb of explosive. Different environments will have varying backgrounds of explosive compounds and their combustion products. It is not clear that sensors sensitive enough to detect 1 ppb or 1 ppt will maintain that sensitivity in the presence of high backgrounds of the same explosive vapor.

WORLDWIDE TECHNOLOGY ASSESSMENT

South Africa	●●	Russia	●●●●	UK	●	United States	●●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Russia uses a technique in which vapor is adsorbed on metal-oxide film. The adsorption of the vapor on the metal film reduces the resistance of the film. The nanonstructure films are sensitive to molecules that can be easily polarized (explosives). Absorption of the molecules onto the boundary layer causes local screening fields, which in turn result in the escape of local electrons.

In the United States other approaches are being pursued. One uses thin sorbent coatings on SAW devices to determine vapor sorption and selectivity. The most sensitive of the new polymers exhibit detection limits for nitrobenzene of a sensitivity of several parts per trillion. Measurements of the transport properties of explosive vapors are used to determine residual trace amounts available for measurement. Bolometers are being used to measure responses to trace amounts of complex vapors, that is, explosive vapor plus additional trace vapors.

DATA SHEET III-17.7. EXPLOSIVE ARRAY NEUTRALIZATION

Developing Critical Technology Parameter	Individual small shaped charges can be used to initiate detonation of buried land mines as they pass through the mine main charge explosive. Matrix arrays of these shaped charges are deployed as a large net with shaped charges at the interstices. The interstices are approximately 15 cm apart so that at least one shaped charge will penetrate any antitank mine covered by the matrix array. The matrix array is deployed after being launched by a rocket over a suspected mined area.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Unique production assembly will be required to produce expandable arrays consisting of shaped charge warheads connected with primacord.
Unique Software	None identified.
Technical Issues	The performance of shaped charges against TNT-filled landmines is an important issue because of the insensitivity of TNT and the diverse methods used to fill TNT-based landmines.
Major Commercial Applications	None identified.
Affordability	Because the array is consumed in its mine-neutralization mission, the size and cost of the array will determine its ultimate military utility.

RATIONALE

Because minefields are covered by both direct and indirect fire, a premium is placed on countermine systems that can quickly neutralize a cleared path from a standoff position. A rocket-propelled net consisting of an array of shaped charges connected by primacord can be placed on suspected minefield locations from significant standoff distances. The array of shaped charges can be detonated over a portion of the minefield to provide a clear path or lane through the minefield. This development is consistent with the standoff minefield breacher ORD and would provide an ideal complement to the standoff minefield detection system.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

Recent shaped-charge measurements against mine main charge explosives have been made in the Netherlands, but there has been no attempt to produce a prototype system for humanitarian demining missions. In the United States, the explosive array has been developed for the Army. Tests of both the net launch and shaped-charge kill have been successfully completed.

DATA SHEET III-17.7. GPR DETECTION

Developing Critical Technology Parameter	GPRs operating between 0.3–15 GHz can provide reliable detection of objects to tactical mine burial distances (10–15 cm). Increasing computing performance helps evaluate radar returns from SARs in real time to provide detection for both hand-held and vehicle-mounted mine detection applications.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Each radar array demands separate software be developed to interpret radar return signals.
Technical Issues	Dielectric constant of main charge explosives and that of plastic cases are nearly the same value as that for sand. Therefore, this approach is least sensitive to small AP mines buried in sand. Technique is also vulnerable to heavy moisture conditions and surface reflections.
Major Commercial Applications	Detection of buried pipelines and cables.
Affordability	This is a moderately expensive technology in development and potentially inexpensive for mass production.

RATIONALE

Recent tests show high probability of detection against both plastic and metallic antitank landmines with significantly lower false alarm rates than were previously attained using any other detection technology. GPR technology is still limited in its ability to distinguish AP landmines from same-size buried clutter. Approach is vulnerable to standing water on the surface of the earth.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●	Japan	●●●	South Africa	●	Sweden	●
United States	●●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

GPR is being used for handheld detection, vehicle-mounted detection, and standoff aerial minefield detection. The European Union interest in humanitarian demining has spawned a number of new investments throughout the European community in GPR, principally for mounting on vehicles to detect antitank mines. France, Germany, UK, Belgium, and Turkey are all investing in a Thomson GPR for research measurements. Elta in Israel has developed a GPR system that has been tested in Canada and the United States. Russia has developed GPR systems to be man portable, as well as for vehicle systems. Five separate North American contractors recently successfully completed advanced technology demonstration (ATD) testing before entering engineering and manufacturing development. GPRs are also being developed in Europe for use on aerial platforms to find entire minefields in humanitarian demining applications. The United States has demonstration synthetic aperture ultra-wideband GPR for aerial platform detection of buried metallic mines.

DATA SHEET III-17.7. PASSIVE IR DETECTION

Developing Critical Technology Parameter	Mines buried in soil near the earth's surface are detectable with passive IR devices for several reasons: the heat capacity of the mine is different from the surrounding soil, so the mine is at a different temperature during most of the diurnal cycle; the amount of moisture above the mine is different from that of the surrounding soil; and the density of the soil put back on top of the mine is different for several weeks after the mine is inserted. As the surrounding soil heats and cools during the diurnal cycle, the mines are differentially heated and cooled so that there are times when the mines are hotter, cooler, or at the same temperature. During the cross-over times, the mines are very difficult to detect. Good results have been achieved in both the mid-wave and long-wave IR bands, with the best results usually occurring 1 to 2 hours after sunrise or sunset, where the mines are at the largest differential temperatures from the soil.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Because the IR signature of the mine changes during the day, software is being developed that will key on specific temperature differences obtained from selected calibrated targets.
Technical Issues	That the mines are best detected during certain periods of the day limits the military utility to certain scenarios and applications.
Major Commercial Applications	There are numerous commercial and military uses of passive IR. The uses for the software being developed to find mines could also be used in humanitarian demining applications.
Affordability	Cost of second-generation FLIRs may limit their military utility to being mounted on ground vehicles for road mine detection or on UAVs for remote minefield detection.

RATIONALE

This technology is important to the future of standoff minefield detection programs both because of its unique capability to detect surface and buried mines from a standoff distance and also because of the relatively small size and weight requirements it imposes on potential platforms. This approach is limited in that its best performance occurs during specific parts of the day. The technology has been utilized to meet the ORD requirements for the standoff minefield detection system.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●●	Italy	●	Japan	●●	Norway	●
South Africa	●	Sweden	●	UK	●●●●	United States	●●●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

Although many European nations have well-developed FLIR and line scanner production capabilities, the use of this technology for mine and minefield detection is only now emerging as new money is being made available for humanitarian demining research. France, Germany, Belgium, the Netherlands, the UK, and Turkey are all currently pursuing research and development programs that include the use of FLIRs for mine detection from both land and aerial vehicles. The United States has extensive experience in the development and testing of both line scanners and FLIRs from airborne, land vehicle, and dismounted soldier platforms.

DATA SHEET III-17.7. LASER-INDUCED IR POLARIZATION

Developing Critical Technology Parameter	Man-made objects such as the flat and smooth surfaces on mines polarize light differently than the surrounding soil and vegetation. When a laser source illuminates a specific ground area, the land areas exhibiting substantially unique returns can be examined for the presence of mines. Because the same signal also provides information on the size and placement of the suspected object, the approach can be particularly effective in finding surface mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Unique software is being developed to examine specific polarizations, but also to identify mine fields and mine field patterns.
Technical Issues	Effectiveness of this approach is limited to detection of surface landmines. Polarization data can be concomitantly used with reflected and passive IR data to better discriminate mines from clutter.
Major Commercial Applications	Humanitarian demining also has requirements to determine the placement and extent of minefields from standoff distances.
Affordability	This is an expensive technology to develop and produce.

RATIONALE

Laser-induced IR polarization returns provide a standoff capability to detect mines and minefields. An active system provides day and night capability against all surface laid minefields. Systems can be made small enough to mount on UAVs. This technology is being exploited to attempt to meet the requirements the airborne standoff mine detection system (ASTAMIDS) ORD.

WORLDWIDE TECHNOLOGY ASSESSMENT

Finland	●	Germany	●	India	●	Italy	●
Japan	●	Norway	●	Pakistan	●	South Africa	●
Spain	●	Sweden	●	UK	●	United States	●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

Although the use of polarized signals to discriminate man-made targets is broadly available, its development for use in countermine has been limited to research and development programs in both the UK and the United States.

DATA SHEET III-17.7. NEUTRON ACTIVATION DETECTION

Developing Critical Technology Parameter	Natural californium sources that emit thermal neutrons are used to produce a prompt gamma from nitrogen in explosive compounds. The approach has been to use neutron activation as a confirmatory sensor to detect the presence of explosive compounds in areas where other mine-detection systems have discovered some form of subsurface anomaly.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Specific software has been developed to process the raw signal counts.
Technical Issues	Process identifies nitrogen and nitrogen compounds. Process is not specific to explosives or explosive types. Obtaining sufficient signal to background has limited the ability of this approach to finding AT mines and large AP mines (main explosive charge greater than 1 lb).
Major Commercial Applications	This approach has been used as an explosive detector at a few airports. Although very expensive, this approach could also be used in some humanitarian demining applications.
Affordability	Number, quality, and calibration of sensors are all major cost drivers in what will be a large expensive system.

RATIONALE

Thermal neutron activation measures nitrogen directly and through this measurement gives location of the explosive. For buried mine detection, the system must interrogate metric tons of soil. Different environments may require different software to compensate for background clutter. Current systems use natural radioactive source. Fielded systems would need to use neutron generators. This technology approach is well suited as a confirmatory sensor for the GSTAMIDS ORD.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

SAIC has pioneered the use of this detection technology in both Canada and the United States. Because of the size and cost of the experimental hardware, many nations look for further development to come from North America. That present systems use natural radioactive sources also limits broader participation. The development of neutron generators may broaden the appeal of this technology for countermine and humanitarian demining.

DATA SHEET III-17.7. WATER JET DETECTION

Developing Critical Technology Parameter	The concept is to use the stream of water hitting a hard target to carry the reflected sound back to a detector. Although sensors placed directly on the external surface of UXO and mines can measure the sound velocity in the encased explosive, it has never been experimentally shown that the same types of measurement are possible through the water jet stream. Better detection results have been achieved using hot water to heat the mine so that the thermal signature of the mine is contrasted against the colder soil.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Specific software must be written if the concept can be demonstrated experimentally.
Technical Issues	Experimental demonstration of concept.
Major Commercial Applications	If the approach can be demonstrated, it could be used to find buried utility lines and sewers.
Affordability	The approach is moderately expensive.

RATIONALE

Arrays of small, high-pressure water jets can be used to rapidly penetrate several inches of soil cover. The scattering of the water jet by buried objects can be monitored to detect objects with different sound velocities. The technology approach is compatible with the GSTAMIDS ORD.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States ●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

Although water jet technology is widely commercially available, the United States appears to be the only country currently investigating the use of water jets for mine detection. Improved detection rates have been demonstrated when hot water is used to heat mines so that the thermal signature may detect by FLIRs.

DATA SHEET III-17.7. CHEMICAL NEUTRALIZATION

Developing Critical Technology Parameter	Many countermine situations require that mines be neutralized in situ with no collateral effects. Although explosive ordnance demolition procedures exist to deal with these types of situations, the reality of the combat situation is that EOD personnel may not be available or too many mines may be involved to make the EOD approach viable. In these cases, mine neutralization could be effected by combat engineers if they had a device that would penetrate the mines and place chemical reagents into the main charge explosive. These techniques have been demonstrated using solvent/reagent solutions to rapidly react the explosive to a nondetonable mass.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Encapsulation of the solvent/reagent system in containers compatible with current Army depots and logistics systems.
Major Commercial Applications	This approach is ideal for humanitarian demining situations, in which it is important that the mines be destroyed quickly and in place.
Affordability	Inexpensive system to procure and field.

RATIONALE

Methods that chemically change the mine main charge explosive into a nonhazardous residue are needed for future peacekeeping operations. To be effective, the chemical system must quickly chemically react a large variety of secondary explosives. Early systems used both a solvent and a reagent to quickly react the mine main explosive charge. There is currently no ORD or other requirement document for this technology. Attempts have been made to use this approach in humanitarian demining systems.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●●

Legend: Extensive R&D   ●●●●   Significant R&D   ●●●   Moderate R&D   ●●   Limited R&D   ●

The recent interest in humanitarian demining has renewed international interest in the disposition of mines and UXO. Early efforts in the United States used acetone and isopropylamine systems to quickly (15 min) react the main explosive charge in large antitank mines. Current applications for humanitarian demining lead to shorter (5 min) reaction times for smaller antipersonnel landmines.

DATA SHEET III-17.7. FLAIL CLEARANCE AND NEUTRALIZATION

Developing Critical Technology Parameter	Flails have been used since World War II to neutralize land mines. The counter-rotating flail acts like an end mill clearing the soil and mines. The clockwise rotating flail can detonate simple pressure fuzed mines and cause catastrophic mechanical damage to the mine body—leaving the primary fuze explosive and booster still in vicinity of main explosive charge material.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	The rate of mine neutralization is generally very slow and not compatible with maneuver operations. The approach is very useful for peacekeeping missions in which certain areas must be cleared to house troops or equipment.
Major Commercial Applications	None identified.
Affordability	The flail is a large, massive system that can only be used on the front of large tanks or earth movers.

RATIONALE

Flails mounted on the front of slow-moving vehicles have historically been used to remove mines for off-route applications. The process is generally limited to speeds of 1–2 mph and is best used for clearance in areas not under indirect or direct fire. The United States has developed a small, remotely controlled trail flail that can be used to remotely clear paths through wooded combat trails or along the edge of combat roads where antipersonnel mines have been placed by the enemy.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●●	UK	●●●●	United States	●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Germany and the UK are the major suppliers of flails for countermine and humanitarian demining purposes. The German flail produced by MAK is designed to interface with the glacis of armored combat vehicles. The British Aardvark flail design uses a captive, protected prime mover.

DATA SHEET III-17.7. HIGH-PRESSURE FLUID JET NEUTRALIZATION

Developing Critical Technology Parameter	Optimization of soil and mine case perforation against a wide variety of metal- and plastic-cased mines can be achieved with fluid jets driven at high pressures. The fluid used by the jet can also contain chemicals/solvents to attack the main explosive charge of land mines. Devices that can be backpack mounted have been demonstrated for use by dismounted troops. Larger devices have been demonstrated from tactical vehicles.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	The amount and type of fluids to be used for neutralization is strongly affected by the number of false alarms that could be anticipated by a complementary mine detection systems.
Major Commercial Applications	Water jets are already in use commercially for a wide variety of landscaping and gardening applications.
Affordability	This approach is moderately expensive to produce and field.

RATIONALE

High-pressure fluid jets are currently used in a number of commercial cutting and gardening applications. High-pressure fluids can rapidly penetrate a soil overburden and perforate a mine casing. A variety of chemicals could be used to react the mine main charge explosives. This technology approach is compatible with the current Mine Hunter/Killer S&T program that is working on block improvements to the GSTAMIDS.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●	Japan	●●	South Africa	●●	Sweden	●●
UK	●●●●	United States	●●●●				

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

While water jets are commercially available throughout the world for agricultural and mining applications, the principal focus of their use has been for EOD. The UK has long used this technology to neutralize terrorist devices.

DATA SHEET III-17.7. LASER DOPPLER VIBROMETER DETECTION

Developing Critical Technology Parameter	Laser Doppler vibrometer detection is an emerging technology that requires line-ofsight access to the soil covering the land mine. A laser Doppler vibrometer measures the soil velocity above and around the buried mine that has been stimulated by an acoustic sound source. The approach is consistent with developmental efforts to decrease the false-alarm rates currently exhibited by EMI and radar technology approaches.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Performance in dry, hard soils has not been established. This performance data is necessary to demonstrate the efficacy of this approach in adverse environments. Image acquisition times are currently lengthy and would confine the technology's immediate utility to that of a confirmatory sensor.
Major Commercial Applications	This approach could be used in peacekeeping and humanitarian demining applications.
Affordability	This is a moderately expensive technology to develop and procure.

RATIONALE

Acoustic sources coupled into the earth produce scattering by buried objects. The soil velocity is measured by the laser vibrometer. The current approach is time consuming and relies heavily on knowledge of sizes of mines to classify the target as a mine. This technology approach is compatible with the requirements for a confirmatory sensor the GSTAMIDS ORD.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●	Japan	●●	South Africa	●●	Sweden	●●
UK	●●●●	United States	●●●●				

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

Laser vibrometers are used for R&D activities supporting a number of commercial products. The University of Mississippi is doing work on the use of laser vibrometers to detect buried mines for both countermine and humanitarian demining applications.

DATA SHEET III-17.7. NUCLEAR QUADRUPOLE DETECTION

Developing Critical Technology Parameter	NQR can provide specific information on nitrogen-containing and halogenated compounds. NQR is basically a radio-frequency spectroscopy technique that results from the variation of the nuclear electric field from sphericity.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Spin lattice relaxation times for TNT limit detection approaches to confirmatory sensors. The SNR is a problem for small mines filled with TNT. The NQR process is vulnerable to ambient radio signals and other noise sources. NQR is also vulnerable to areas with high backgrounds (explosive fragments thrown over interrogation area).
Major Commercial Applications	NQR technology has been investigated as explosive detectors in airports.
Affordability	This technology is expensive to develop, but could be less expensive to procure.

RATIONALE

The NQR process works best when explosives are placed in a controlled geometry with appropriate RF shielding such as is found in luggage inspection machines in airports. Buried landmine detection is a one-sided measurement. There is greater difficulty in shielding extraneous RF noise in the single-sided mine detection configuration. Initial success has been demonstrated with RDX explosives. The NQR approach requires a different frequency to detect other types of explosives such as TNT. TNT detection demonstrated with time constants $T1$ of approximately 3–5 sec.

WORLDWIDE TECHNOLOGY ASSESSMENT

Russia	●●●	UK	●●●●	United States	●●●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

Research and development of NQR for mine detection is currently in progress in Russia, the UK, and the United States. The U.S. Army will begin a program to develop NQR as a confirmatory sensor for vehicle applications in the next year.

DATA SHEET III-17.7. PLOW CLEARANCE AND NEUTRALIZATION

Developing Critical Technology Parameter	Plows are a traditional method for moving mines from the path of large tracked vehicles such as tanks. For track-width mine plows, speeds of 7–10 mph can be achieved. Full-width plows are being developed, but it is not anticipated that these will function at speeds at or greater than 3 mph. The plow removes all types of mines to depths of 8 in. and has been successfully deployed by many nations in several wars.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Full-width plows need depth control to deal with variations in Earth's crust. Failure to anticipate large loads will result in unnecessary slowing and stopping. To be useful in combat situations where minefield breachers are exposed to direct and indirect fire requires that the platform pushing the plow proceed through the minefield at the fastest possible speed.
Major Commercial Applications	This technique can also be used in humanitarian demining situations.
Affordability	Although the technology is straightforward, its implementation is large, heavy, and costly.

RATIONALE

Track-width and full-vehicle-width plows mounted on armored vehicles can remove the top soil and buried mines to a depth of approximately 8–12 inches. This form of rapid clearance is needed for rapid minefield breaching where the breaching forces are under fire. Many countries field some variation of track-width mine plows.

WORLDWIDE TECHNOLOGY ASSESSMENT

Canada	●●	China	●●	Denmark	●●	Egypt	●●
Germany	●●●	South Africa	●●●	Sweden	●●●	UK	●●●●
United States	●●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Plows are universally available for agricultural use. The use of plows for mine clearing certainly dates to before World War II. Many countries are investigating the use of plows that protect the full width of combat vehicles as opposed to the generally used track-width plows now in service.

DATA SHEET III-17.7. MINE ROLLER

Developing Critical Technology Parameter	The use of mine rollers pushed by a tracked vehicle such as a tank is the classic method for defeating simple pressure-pulse mines both on and off road. The simple countermeasure to the mine roller is the use of a double-impulse fuze, in which the first impulse by the roller is ignored and the fuze is actuated by the first bogey wheel of the tank. Mine rollers can also be effective in clearing modern magnetic fuzed mines, particularly under the track of the roller.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Survivability of roller banks; repeated exposure to mine blast overpressures leads to failure of the roller bank assembly.
Major Commercial Applications	None identified.
Affordability	None identified.

RATIONALE

Large rollers, mounted together in separate roller banks in front of the tracks of armored vehicles, are used to detect road mines and to proof areas against simple, single-impulse mine fuzes. The method combines speed together with a roller survivability generally limited to two mine detonations at the edge of the roller bank. The survivability of the mine roller is greater if the mine detonations occur under the center of the roller bank.

WORLDWIDE TECHNOLOGY ASSESSMENT

Canada	●●●●	China	●●	Denmark	●●	Egypt	●●
Germany	●	South Africa	●●●●	UK	●●●●	United States	●●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Rollers have been used since World War II to actuate single pressure plate landmines. Most armies throughout the world have rollers that can be pushed from an armored platform to assault minefields. Lighter disposable rollers have also been affixed to lighter platforms for road sweeping and clearing missions.

DATA SHEET III-17.7. VAPOR/PARTICLE DETECTION

Developing Critical Technology Parameter	Detection of explosive vapor that has leaked through a mine structure or has been emitted by small amounts of explosive in contact with the outside surface of a mine can play an important role with other detection techniques in explosive verification. The difficulty with this approach is that only small residual amounts of trace vapor remain at the earth's surface above the buried mine. TNT has a very low vapor pressure, and recent DARPA measurements indicate that it is difficult to find trace amounts even in the vegetation above the buried mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Unknown and variable vapor/particle emission rates for sealed landmines make it problematical that vapor detection will be a robust method to detect buried mines. Explosive compounds clutter the battlefield, and it is difficult to predict the ability of explosive sniffers to retain sufficient sensitivity to detect trace explosive amounts in large explosive vapor backgrounds.
Major Commercial Applications	Explosive sniffers are being used in airports and for building security. This approach is also being exploited for use in humanitarian demining.
Affordability	This is a moderately expensive technology to develop and field.

RATIONALE

Chemical detectors are an excellent tool to find trace amounts of explosives; however, for the countermine role, the system must detect explosives in a wide range of environments and over clutter differences differing by many orders of magnitude.

WORLDWIDE TECHNOLOGY ASSESSMENT

Canada	●●	Germany	●	South Africa	●●●●	UK	●●
United States	●●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

Chemical-vapor-detection technology is in use in many of the world's airports today. South Africa uses a variety of chemical-vapor-detection schemes coupled with the use of canines for explosive detection.

SECTION 17.8—SEA AND LITTORAL REGION MINE COUNTERMEASURES

Highlights

- Mine hunting systems capable of stream, tow, and recovery operations from helicopters and that use on-board sonars for mine detection and laser sensors for mine identification are being developed.

- Airborne lidar mine-detection systems are being developed to rapidly detect moored and floating mines.

- New software that uses both archival and in situ environmental data in mine countermeasure equipment is being designed to improve "through the sensor" mine detection and mine identification capabilities.

- Ultrasensitive, optical-fiber, magnetic-field sensors and superconducting quantum interference devices (SQUIDS) are being developed for detection of metal ocean mines.

- Superconducting magnets are being developed to project magnetic flux densities sufficient for shallow water minesweeping of mines that use magnetic fuzes.

- Spectral shaping of plasma discharge acoustic sources are being used to emulate shiplike acoustic signatures for minesweeping applications.

- Electromagnetic and acoustic sensors are being fused for detecting proud and buried mines in very shallow water environments.

- Low-frequency synthetic aperture sonars are being developed for detecting mines on or in the ocean floor. Mid-frequency synthetic aperture sonars are being developed for long-range detection and classification of bottom mines.

- Toroidal volume search sonars are being developed for high area coverage of mines.

- Streak tube imaging lidar, range gate lasers, and laser line scanners are being developed for mine identification.

- Laser sensors are being developed for fluorescence detection of plastics and other anthropogenic compounds dissolved in seawater.

- Expendable fiber-optic tethered vehicles with sonar and video links and that can be deployed from airborne vehicles to hunt and kill individual mines with shaped charges are being developed.

- Rocket-propelled explosive net arrays and line charges are being developed for the standoff neutralization of mines in the surf zone.

- Supercavitating projectiles fired from airborne platforms are being developed to rapidly neutralize sea mines.

- Precision-guided submunitions are being developed to neutralize beach zone mines and obstacles.

OVERVIEW

The sea offers strategic and tactical mobility to those who control it. During most of the 20th century, however, control of the sea has been focused on the requirements to transition to war on land. The requirements to ferry massive forces ashore and then provide logistic support to those forces has severely limited maneuverability and has restricted choices of landing areas. In the future, the United States will face many different threats to its security and national interests. Most likely, these threats will be in the littorals because more than 75 percent of the world's population and its largest and capital cities are on or near coasts. The requirement to project power ashore means the ability to perform forced entry as well as disaster relief. Both sea mines and mines in the littoral regions limit the

ability to maintain pace and sustain operations. It is essential to shape the battlespace in a theater of operations to deal with mines quickly and effectively.

Mines are inexpensive weapons of choice for most third world countries, and can be highly effective when employed in the littoral regions, shipping lanes, and ports. Mine countermeasures includes knowing where the mines and surf/beach zone obstacles are, the ability to clear mines and obstacles, and the ability to obstruct or to destroy mine-laying platforms or mine stockpiles. Mine countermeasure equipment and technology is needed to support four different types of operations: (1) mapping, survey, and intelligence operations; (2) surveillance operations; (3) organic mine countermeasure operations; and (4) dedicated mine-countermeasure operations. Therefore, mine-countermeasure operations—minesweeping and jamming, mine/minefield hunting, and mine/obstacle neutralization—require a spectrum of technology skills ranging from the use of national mapping and intelligence assets to specific mine-countermeasure assets.

Shallow-water influence minesweeping relies on projecting false magnetic and acoustic signatures that "trick" mines employing influence sensors into firing the mine prematurely. Current minesweeping devices use a helicopter to tow a small hydrofoil sled that contains both an electrical generator and a long cable that conducts a large current to project false magnetic-flux densities. MCM ships (Avenger Class) also stream long cables and acoustic devices to project false magnetic and acoustic signals to sweep the mines. New superconducting sources together with plasma discharge acoustic sources are being developed to emulate simultaneously a ship's magnetic and acoustic signatures.

A variety of organic mine countermeasures equipment is being developed to be used in different situations and environments. The AN/AQS–20/X is a helicopter-deployed sensor that uses sonars and laser sensors to detect, classify, and identify bottom and tethered mines. The airborne laser mine detection system uses blue-green laser reflections to rapidly detect moored and floating mines. This system will provide both quick-reaction airborne mine reconnaissance and percursory reconnaissance for dedicated mine countermeasure units. The remote minehunting system (RMS) is an independent platform that will provide surface combatants an organic system capable of detection, classification, identification, and location of moored and bottom mines. RMS uses the AQS-20/X as its sensor payload. The Airborne Mine Neutralization System consists of an expendable neutralization vehicle that can be deployed from a helicopter. The expendable vehicle includes sonar and video links for mine detection and identification and shaped charges for bottom or deep-moored mine neutralization. A new concept for rapidly neutralizing sea surface mines or mines tethered close to the surface is the rapid airborne mine clearance system (RAMICS). The RAMICS uses supercavitating projectiles fired from a helicopter-mounted machine gun and targeted by a blue-green laser. The organic airborne and surface influence sweep system will use magnetic and acoustics signature duplication and projection to sweep influence mines in shallow waters. The Navy is also developing a submarine-launched and recovered unmanned underwater vehicle, called the long-term mine reconnaissance system (LMRS), capable of conducting clandestine mine reconnaissance. The sonar capabilities are similar to those of the AQS–20.

There are also specific ongoing programs to address mine countermeasures in amphibious assault lanes. In the 40- to 10-ft depth regime, the Navy is developing diver systems, marine mammal systems, and its first small autonomous undersea vehicle. In the surf zone (10 ft to 0 ft) and the beach zone, the shallow water assault breaching (SABRE) system and distributed explosive (DET) systems are being developed to explosively neutralize mines. SABRE consists of rocket-launched explosive line charges to rapidly clear lanes in the deeper portions of the surf zone. DET uses a dual rocket-launched distributed explosive net to create safe lanes through the shallowest portion of the surf zone.

The Mine Warfare Environmental Decision Aids Library (MEDAL) provides analytical tools that utilize archival data for mine countermeasure planning and measurements. In the long term, MEDAL will also provide "through the sensor" capability to improve sensor detection and identification performance as well as feeding "through the sensor" data back to the archives. In addition to being a tactical decision aid for mission, MEDAL is also a post-operations analysis tool and provides the connectivity between all mine warfare platforms and the rest of the battle group or the amphibious ready group. Environmental science and technology programs will also be used "through the sensor" to provide information on mine burial, shock-wave propagation, and optimum probabilities of kill.

Emerging technologies that will be incorporated in mine-hunting platforms include toroidal volume search sonar for rapid, full water column mine searches, synthetic aperture sonars to find mines at the bottom or in the soil at the bottom, and advanced signal-processing techniques. Advances in mine identification are being pursued in the development of laser sensor to detect fluorescence of plastics and other anthropogenic compounds and the use of streak tube imaging lidars. The Navy is also experimenting with an advanced underwater surveillance system that will be capable of detecting ongoing mine operations as they occur. Also, networks of autonomous unmanned vehicles are being pursued. These autonomous systems will employ a navigation and control element, have the ability to fuse multisensor information, and provide data transmission and retrieval. To improve remote sensing, the Navy is developing technologies to exploit satellite and theater imagery, together with environmental measurements of surface waves, wind, current, and bathymetry, to more accurately depict the presence and extent of sea and littoral mines. Because ship-to-objective maneuver (STOM) relies on the rapid and accurate elimination of anti-assault mines and obstacles and the rapid movement of forces and materiel ashore, the placement of explosive line charges and distributed explosive arrays deployed from landing crafts, air cushion (LCACs), is not a viable long-term solution. Here, the Navy is exploring novel ways to kill mines and obstacles in the surf zone, on the beach, and in the beach exit zone. Air-launched and gun-fired precision-guided munitions with antimine reactive darts and antiobstacle, continuous-rod warheads are maturing technologies in this area.

RATIONALE

The end of the cold war has shifted the focus from open sea strategies to that of joint expeditionary force operations in the littorals. Concomitant with this change, the potential for mine warfare to frustrate U.S. power projection is greatly expanded. Effective mine countermeasures are required if the United States expects to conduct operations in distant locations and make its presence felt in a timely manner. Mine countermeasures are required to maintain a credible presence and to shape and dominate the battlespace, if necessary.

Increasingly, the United States has been involved in peacekeeping missions. The insertion of naval and land forces could be effectively stalled or jeopordized by the use of naval, littoral, and land mines. From the sea, strategies that treat the sea as maneuver space cannot project the threat of multiple land alternatives when specific ports and coastal areas have been mined. Thus, the role of naval forces in peacekeeping missions could be offset effectively by the use of sea and littoral mines.

The first mine countermeasure operations will involve the use of national and tactical assets to define areas and ports of entry that are not mined. Because the number of ports or accessible landing zones may be limited, it is very likely that entry areas may be mined. Therefore, it is vital that mine-hunting and mine-neutralization systems be available at the tactical level. Specifically, both mine-detection sensors and mine-neutralization systems must work in a variety of sea-state and littoral environment conditions. This limits the number and type of technologies that will be effective and places demands on development of complementary systems at tactical and strategic levels.

The role of the speed of search in mine detection is covered in Section 17.7—Landmine Countermeasures.

Country	Sec. 17.8
Australia	●●●
Canada	●
Denmark	●
France	●●
Germany	●●●
Italy	●●
Norway	●
Russia	●
South Korea	●
Sweden	●●
UK	●●●●
United States	●●●●

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

The leaders in mine-detection technology for sea mines are the United States and the UK with extensive R&D, followed by Australia and Germany with significant R&D, and Sweden, Italy, and France with moderate R&D.

The U.S. Navy reacted quickly to the lessons from the Gulf War by placing increased emphases on mine countermeasures both at sea and in the littorals. Increased R&D has spawned technology developments in superconducting magnets, SQUIDs, new lidars, and sonars. Many of the new developments are shared with and among allied forces. Sweden, Canada, and Australia have laser depth finders for airborne systems. Germany, France, the UK, and Australia are investing in synthetic aperture sonars for mine detection. Australia, the UK, and Germany share the U.S. interest in developing explosive net arrays, with Germany involved with the United States in developing hydrocode models. Optical-fiber magnetic-field sensors have been identified as a future thrust area by South Korea.

Minesweeping is being pursued by most of the NATO nations. The UK has developed 3-axis coils to be deployed from a small, remotely controlled watercraft. Australia and Denmark have developed torpedo-shaped cylinders containing permanent magnets for minesweeping activities. The United States has demonstrated a super-conducting coil technology for minesweeping. Expendable underwater mine hunters are being developed by Germany, the UK, Italy, and Norway.

For rapid airborne clearance systems, Russia has developed a supercavitating technology to propel projectiles through the water. The UK is developing semi-armor piercing antimine charges. The United States rapid clearance system is built around an airborne lidar system to detect surface, moored, and tethered mines coupled to supercavitating projectiles.

Physics-based models are being developed at the Naval Research Laboratory and in the UK to identify those spatial sediment properties which result in significant changes or errors in mine detection and identification. These developments will be used to build "through the sensor" improvements into mine countermeasure systems as they are introduced into new environments and scenarios. Both the United States and the UK are developing NQR techniques to detect antipersonnel and antitank mines.

LIST OF TECHNOLOGY DATASHEETS
III-17.8. SEA AND LITTORAL REGION MINE COUNTERMEASURES

DATA SHEET III-17.8. MODULATED PULSE LIDAR

Developing Critical Technology Parameter	Modulated pulse lidar systems are used to enhance the contrast of underwater objects. A multimodulation frequency transmitter and wide-bandwidth, large-area optical detector are being developed [0.5–10 GHz, high optical power (>10 kW), pulsed (10–15 nsec), blue-green (532 nm) optical transmitter]. Field test results conducted at 0.15- and 5-m depth demonstrated improved modulated pulse target returns due to backscatter clutter rejection. The modulated pulse lidar system has the potential to improve lidar system search rates by more than an order of magnitude for mine localization. Critical technologies for development of this technology include large-area, high-speed photo detectors and high-speed optical modulators for high-capacity systems.
Critical Materials	Critical technologies for development of this technology include the need for materials for large-area, high-speed photo detectors and high-speed optical modulators for high-capacity systems.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Optimized sensor performance depends on the development of software that includes ocean optical characteristics.
Technical Issues	Water clarity and turbidity have a large impact on the benefits of this system. Theoretical models need to be developed to better understand experimental measurements so that appropriate technological improvements can be made.
Major Commercial Applications	This approach is applicable to both biomedical and communications applications.
Affordability	Although most of the parts are commercially available, incorporation of this system into a small number of prototypes will be expensive.

RATIONALE

Small shallow underwater targets are contrast limited in conventional lidar systems. A multiple frequency system (0.5–10 GHz), high optical power (>10 kW), pulsed (10–15 nsec), blue-green (532 nm) optical transmitter has been developed to measure water and target frequency spectra. Modulated lidar echo returns from 0.15- to 5-m depths provide significant improvements over that obtainable from conventional lidars. Modulated pulse lidars can provide improved mine location and identification in underwater applications.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●●	Canada	●●	Sweden	●●	United States	●●●
Legend:	Extensive R&D ●●●●	Significant R&D ●●●		Moderate R&D ●●		Limited R&D ●	

The United States and Australia have the lead in this technology with significant R&D.

DATA SHEET III-17.8. TOROIDAL VOLUME SEARCH SONAR

Developing Critical Technology Parameter	Toroidal volume search sonars are being developed for full water column, high coverage rate detection and classification of moored and close-tethered mines in deep water. A 360-deg beam pattern provides a 1,500-m diameter path width when mounted on underwater unmanned vehicles.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Advanced signal-processing systems will be required to keep pace with the 6 square nmi/hour coverage rate of this system.
Technical Issues	Performance of this system in water as shallow as 60 ft will test signal-processing capabilities to deal with both surface and bottom reflections.
Major Commercial Applications	None identified.
Affordability	No cost issues have been identified.

RATIONALE

Rapid area searches for moored and close-tethered mines are required for safe operation as marine forces approach landing areas. The 68-kHz 360-deg beam pattern can provide volume search, as well as surface and bottom coverage with narrow beamwidth patterns. Because the system will be operated on an underwater unmanned vehicle, the system can also be used in clandestine operations.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States is the leader and sole developer of this technology with significant R&D.

DATA SHEET III-17.8. SYNTHETIC APERTURE SONAR

Developing Critical Technology Parameter	Synthetic aperture sonar technology provides high-resolution detection, classification, and identification of proud and buried mines in water depths to 25 m. Prototypes have been tested using high, mid, and low frequencies. The high-frequency synthetic aperture sonar operates at 180 kHz and is capable of 2.5-cm resolution for mine identification at short ranges. The mid-frequency synthetic aperture sonar is striving to achieve detection/classification ranges of 500 m or more. The low-frequency synthetic aperture sonar operates at 20 kHz and provides 7.5 cm × 7.5 cm resolution for detection and classification of proud and buried mines. At the lower resolution, the system is capable of covering 0.36 square nmi/hr.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Advanced signal processing is required for mine identification and for motion compensation.
Technical Issues	The need for mine identification in high-clutter areas will limit coverage rates and the time available to use this technology in operational environments. A sister system to reacquire and identify mines from GPS coordinates supplied by the synthetic aperture sonar could significantly reduce mission times where clutter is a problem.
Major Commercial Applications	Underwater recovery of artifacts and valuables from sunken ships.
Affordability	No cost issues have been identified.

RATIONALE

Bottom and buried mines pose a series threat to landing forces. Detection and identification of mines is required in high-clutter, shallow water areas. The synthetic aperture sonars are designed to operate in a fast scan mode, as well as in a high-resolution mine-identification mode. Identification of clear lanes and mined lanes is required before amphibious assaults can be initiated. The development of this system to be compatible with underwater unmanned vehicles enables its use in clandestine operations.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	France	●●●●	Germany	●●●	United Kingdom	●●
United States	●●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States and the UK are the leaders in this technology with extensive R&D programs, followed by Germany with significant R&D efforts and the UK and Australia with moderate R&D efforts.

DATA SHEET III-17.8. STREAK TUBE IMAGING LIDAR

Developing Critical Technology Parameter	The streak tube imaging lidar uses a pulsed blue-green laser and a fixed cylindrical lens to project a fan beam beneath a vehicle onto the ocean floor. Conventional optics image the illuminated stripe onto a slit photocathode of the streak tube. Electrons from the photocathode are electrostatically accelerated onto a phosphor anode to form a 2–D range azimuth image for each laser pulse. The pulse rate of the laser is synchronized to the forward speed of the vehicle so that the in-track dimension is sampled in a push broom fashion. The 3–D image is then processed to image both moored and bottom mines.The streak tube imaging lidar will provide a 3–D image at altitudes of 12 m above the ocean floor at speeds to 12 knots
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Only early prototypes exist, so no test or inspection equipment has been identified.
Unique Software	The 3–D images will require special software, particularly for the high sweep rates intended for this sensor.
Technical Issues	Although the design resolution has been verified in clear water tests, the performance of the system in other environments has not been established. Less than desired resolution will result in more sensor passes per unit area.
Major Commercial Applications	The technology is applicable to environmental monitoring.
Affordability	No cost issues have been identified.

RATIONALE

The objective of streak tube imaging lidar is to develop a mine identification capability to be used after detection and classification of minelike objects to reduce the number of contacts that must be prosecuted. Reducing the number of contacts that must be prosecuted significantly decreases the time it takes to clean an area of mines. The streak tube imaging lidar will be an integral part of the AN/AQS–20X system and will be deployed from a helicopter or from a remote minehunting system. Bottom and close-tethered mines will be detected from the AN/AQS–20/X underwater towed vehicle at tactically significant speeds, swath widths, and standoff ranges. The streak tube imaging lidar will provide a 3–D image at altitudes of 12 m above the ocean floor at speeds to 12 knots.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States   ●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States is the leader and sole developer of this technology.

DATA SHEET III-17.8. FLUORESCENCE DETECTION OF PLASTICS

Developing Critical Technology Parameter	The objective is to develop a compact laser-induced fluorescence sensor that can detect trace levels of chemical substances on mines in seawater. Fluorescence of natural organic matter will constitute the background signal. Analyses of mine components has shown that marine epoxy resins have fluorescence characteristics that serve as fingerprints of the individual components that make up the epoxy.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	To date, only laboratory instruments have been used to establish technical feasibility.
Unique Software	None identified.
Technical Issues	The principal issue is the rate at which mine construction elements will leach to the surface of the mine case. Although a unique fingerprint could be developed, mines without leachates would not be detected. Also, fluorescence levels, water transparency, and siltation rates could limit the range at which mines could be detected.
Major Commercial Applications	None identified.
Affordability	No cost issues have been identified.

RATIONALE

Divers remain a major resource for mine hunting. The use of laser-induced fluorescence sensors to detect mines speeds up a slow and dangerous mission. Used in underwater unmanned vehicles, this approach could be an important part of the mine identification process.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States ●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

DATA SHEET III-17.8. EXPLOSIVE NET ARRAYS

Developing Critical Technology Parameter	Because water is an incompressible medium, water transmits shock energy more efficiently than air. Explosive net arrays detonated in water provide sufficient energy to destroy mines and mine casings in water. Explosive net arrays are an efficient method of covering specific water areas to breach a safe landing lane for amphibious vehicles.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Unique production and assembly will be required to produce expandable explosive arrays.
Unique Software	None identified.
Technical Issues	The performance of these arrays in the surf zone against all mine types needs to be validated experimentally.
Major Commercial Applications	None identified.
Affordability	Because the array is consumed in its breach mission, the size and cost of the array will determine its ultimate military utility.

RATIONALE

Because breaching minefields plays such a pivotal role in successful amphibious assaults, systems that can quickly and efficiently created breached lanes are critical to mission success. Rocket-propelled explosive arrays can be quickly placed on suspected mined areas. The detonation of these explosive arrays provides a clear path or lane through the minefield. This net array can also be used with shaped charges at each interstice of the array to neutralize buried mines.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●	Germany	●●●	United Kingdom	●●	United States	●●●●
Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D ●

The United States has the lead in this technology with extensive R&D, followed by Germany with significant R&D, and the UK and Australia with moderate R&D.

DATA SHEET III-17.8. OPTICAL FIBER MAGNETIC FIELD SENSORS

Developing Critical Technology Parameter	Fiber-optic gradiometers are being developed for shallow water mine detection and classification. An extrinsic Fabry-Perot interferometer (EFPI) configuration with magnetostrictive elements and silicon micromachined substrates is used to create a temperature-insensitive device to detect magnetic field signatures of buried, tethered, and floating ferrous mines. The movements of the magnetostrictive element are monitored using an EFPI configuration. The EFPI is based on the combination of two light waves with a path-induced phase change between them. Current single-axis fiber-optic magnetometers have reached 0.63 mV RMS noise level with resolutions of 35 nT.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Although numerous single-axis fiber-optic magnetometers have been constructed and tested for temperature and magnetic field characterization, production methods have not been defined.
Unique Software	None identified.
Technical Issues	The current program will demonstrate a five-element gradiometer for bearing and magnetic moment detection of ferrous mines.
Major Commercial Applications	Near-term applications include nondestructive object location and classification for geophysical surveying, environmental remediation, industrial manufacturing, and civil engineering uses.
Affordability	These sensors should be relatively inexpensive to produce and use in naval systems.

RATIONALE

Fiber-optic gradiometers have advantages over existing gradiometer mine-detection technologies, including wide operating temperature ranges, low power consumption, and small sizes and weights. The small size and weight together with low power consumption allow remote mine detection by means of manned or unmanned remote-control reconnaissance vehicles.

WORLDWIDE TECHNOLOGY ASSESSMENT

Korea	●	United States	●●				
Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D ●

The United States has the lead in this technology with moderate R&D, followed by Korea with limited R&D.

DATA SHEET III-17.8. MINESWEEPING

Developing Critical Technology Parameter	Most NATO allies have ongoing minesweep technology programs, but they use a variety of different technical approaches. The UK uses 3-axis coils and a small remote-control boat to conduct sweeping operations. Australia and Denmark use torpedo-shaped cylinders containing permanent magnets in towing operations. The United States demonstrated a conductively cooled, low-temperature, superconducting magnet for use in amphibious assault lanes to project magnetic flux densities sufficient to fire mine magnetic sensors. Because sea mines can use complementary acoustic sensors to detect propeller cavitation noise together with the ship's magnetic signature, spectral shaping of plasma discharge acoustic sources is being developed to emulate shiplike acoustic signatures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Simulation tools to evaluate projected magnetic and acoustic signatures against mine logic and sensors are required to establish the effectiveness and extent of mine sweeps.
Unique Software	To accurately establish the effectiveness of the sweep approach, software must be developed to accurately portray a wide range of mine magnetic and acoustic responses.
Technical Issues	Minesweeping equipment is always vulnerable to mine counter-countermeasures that detect the approach of patterned signatures.
Major Commercial Applications	None identified.
Affordability	Minesweeping is a very efficient method to rapidly clear lanes or specific areas of sea mines.

RATIONALE

New mines use fuzes employing more than a single sensor for target acquisition. The co-generation of acoustic and magnetic signatures provides rapid clearance of complex fuzed mines. These minesweep systems can be deployed from remotely controlled surface craft or airborne towed vehicles.

WORLDWIDE TECHNOLOGY ASSESSMENT

Australia	●●●	Denmark	●●●	France	●●	Germany	●●
Italy	●●	Sweden	●●	United Kingdom	●●●	United States	●●●

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States, the UK, Australia, and Denmark have the lead in this technology with significant R&D involvement, followed by Germany, France, Italy, and Sweden with limited R&D.

DATA SHEET III-17.8. EXPENDABLE UNDERWATER MINE HUNTERS

Developing Critical Technology Parameter	An expendable neutralization vehicle to be deployed from airborne mine counter-measure helicopters (MH–53E and SH–60) is being developed. A fiber-optic tethered cable from the expendable vehicle is used for data transfer for sonar and video acquisition of minelike objects and for the shaped charge detonation sequence for mine neutralization. Future expendable systems that can perform autonomous searches without being fiber optically tethered to a manned platform are required. Precise navigation, communications back to a central point, and battle damage assessments are additional required capabilities.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Special software will have to be developed for mine identification and terminal placement and aiming before initiation of the neutralization sequence.
Technical Issues	Given a cluttered near-shore environment, it is critical that an effective and efficient mine identification system, navigation system, communications system, and battle damage assessment system be developed before relatively expensive expendable hunters are committed to neutralization.
Major Commercial Applications	None identified.
Affordability	The principal cost issue is the development of a mine identification capability compatible with the expendable vehicle approach.

RATIONALE

An in-stride organic neutralization capability is needed to maintain pace of maneuver, particularly against the harder to find mines, and to destroy bottom and buried mines. The approach complements the RAMICS that use supercavitating projectiles to attack surface and tethered mines.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●	Italy	●●●	Norway	●●●	United Kingdom	●●●
United States	●●●						

Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D	●

The United States, Germany, Italy, Norway, and the UK have significant R&D investments in this technology.

DATA SHEET III-17.8. RAPID AIRBORNE MINE CLEARANCE SYSTEM

Developing Critical Technology Parameter	Airborne lidar systems that detect surface, moored, and tethered mines are used together with high-speed projectiles that can be fired at the detected mines. Super-cavitating projectiles will have on-board reactive material for mine neutralization. The clear advantage of this type of system is the significant reduction in mine clearance time compared with that of surface or submersible vehicles in mine clearance.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Specific software must be developed for the on-board acquisition, identification, and targeting of mines targeted by the supercavitating projectiles.
Technical Issues	Targeting and hitting a mine from a vibrating, hovering helicopter must be demonstrated at standoff distances up to 1,000 yards. Reacquisition of the mine from GPS coordinates with a narrow field of view lidar must also be demonstrated. The penetration and kill capabilities of the RAMICS rounds must be demonstrated to the deepest keel depth of prospective opponents.
Major Commercial Applications	None identified.
Affordability	For the system to be affordable, the system must provide a high probability of mine kill and a low-cost supercavitating bullet.

RATIONALE

In-stride mine detection and neutralization are required to maintain operational tempo and to avoid operational pauses or interruptions. This approach complements the air-deployable, expendable, underwater mine hunters to provide a surface-to-bottom capability to find and destroy mines. Russia has developed the supercavitating technology. The United Kingdom is developing semi-armor-piercing antimine charges.

WORLDWIDE TECHNOLOGY ASSESSMENT

Russia	●●●	United Kingdom	●●●	United States	●●●
Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●	

The United States, Russia, and the UK have the lead in this technology with significant R&D programs.

DATA SHEET III-17.8. ENVIRONMENTAL FEEDBACK SYSTEMS

Developing Critical Technology Parameter	Existing and future detection systems can be rapidly updated through software updates provided by environmental feedback systems. Physics-based models are being developed that identify those spatial sediment properties which result in significant changes or errors in mine detection and identification. Electrical properties, combined with seismic and acoustic properties, will be developed to provide a rapid method to predict sediment characteristics that affect mine hunting, minesweeping, and mine neutralization. These properties will then be used to provide "through the sensor" improvements to mine countermeasure systems as they are introduced into new environments and scenarios.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Simulation testing will be required to establish through the sensor adjustments and refinements.
Unique Software	Mine countermeasure equipment software must be compatible with reprogrammed data from the environmental feedback system.
Technical Issues	The range and type of acoustic and sediment properties must be defined.
Major Commercial Applications	None identified.
Affordability	No cost issues have been identified.

RATIONALE

The Navy is required to respond to regional conflicts throughout the world; tactical support of these operations within littoral regions requires accurate and timely environmental information. Because of the range in water optical and sediment properties, the ability of mine hunting, minesweeping, and mine neutralization sensors to rapidly and accurately distinguish mines can vary greatly. Provision of accurate, timely data will ensure that mine counter-measure equipment can perform optimally in a wide range of environments and sea states.

WORLDWIDE TECHNOLOGY ASSESSMENT

United Kingdom ●●   United States ●●●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States leads in this technology with extensive R&D, followed by the UK with moderate R&D.

DATA SHEET III-17.8. NUCLEAR QUADRUPOLE RESONANCE

Developing Critical Technology Parameter	NQR can provide very specific information on nitrogen-containing and halogenated compounds. NQR is basically a radio-frequency spectroscopy technique that results from the measurement of the effects due to the interaction of the nuclear quadrupole moment (in nonspheric nuclei) with the electric field gradient of the molecular/ crystalline environment.
	Variations of the electric field gradient in different chemicals serve as the source of the fingerprint for identifying explosives.
	RDX is relatively easy to detect, TNT more difficult. Others are being investigated.
	The advantage of the technique is that it identifies the chemical directly. Also, the SNR limits detection, not clutter as in EMI techniques.
	The disadvantage is that chemicals encased in metal are not excited and cannot be detected directly. For metal-cased mines the instrument is used in a metal-detection mode (as a metal detector)
	NQR detects plastic antipersonnel and antitank mines buried in ground. For antitank mines, the probability of detection is greater than 95 percent at less than 6 in.; for antipersonnel mines it is less than 90 percent at greater than 3 in.
	Detection of mines in salt water is more difficult but not tested yet.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	Spin lattice relaxation times for TNT limit the rate at which mines can be scanned.
	The SNR limits detection, not clutter as in EMI techniques.
	The NQR process is vulnerable to ambient radio signals and other noise sources.
	Detection of mines in shallow sea water has to be tested .
Major Commercial Applications	NQR technology has been investigated as an explosive detector in airports.
Affordability	The technology is expensive to develop, but could be less expensive to procure in quantities.

RATIONALE

The NQR process works best when explosives are placed in a controlled geometry with appropriate RF shielding. Such conditions can be found in airports, where luggage is inspected. Buried landmine detection is a one-sided measurement. There is greater difficulty in shielding extraneous RF noise in the single-sided mine-detection configuration. TNT detection has recently been demonstrated in mines containing 200 g of explosive. With T1 relaxation times of 3–5 seconds, the rate at which an area can be scanned is generally limited to 2–5 minutes per square meter.

WORLDWIDE TECHNOLOGY ASSESSMENT

United Kingdom	●●	United States	●●●				
Legend:	Extensive R&D	●●●●	Significant R&D	●●●	Moderate R&D	●●	Limited R&D ●

The United States and the UK are the leaders in NQR technology. All the world's laboratories that have NMR or MRI capabilities also can potentially do NQR development for mine detection.

DATA SHEET III-17.8. ELECTROMAGNETIC INDUCTION DETECTION

Developing Critical Technology Parameter	New fast-response EMI detectors that use both real and quadrature data to determine the time constant rate of decay of mine targets have been developed. These new data provide the opportunity to detect and classify mine targets. This additional information also provides a basis for rejection of clutter, which will result in fewer false alarms. This new technique may also be able to detect the void produced by plastic mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Special coils must be developed that can both transmit and detect time constants on the order of 1 μsec or less. The time constants associated with different soils and their attendant moisture must also be measured and appropriately archived.
Unique Software	New software must be developed to accurately and quickly evaluate these microsecond interrogations.
Technical Issues	Development of physics-based models to help identify and separate mine and clutter objects is necessary, particularly in forming a rational basis to reject the even larger amounts of clutter associated with interrogating this larger spectrum. The use of these detectors in wet soil against small mines is also problematic.
Major Commercial Applications	Coin, relic hunting detectors, or commercial detectors to detect metal pipes in the ground or behind walls.
Affordability	Technology is relatively inexpensive and straightforward.

RATIONALE

EMI detectors are the most ubiquitous mine- and relic-hunting detectors. High thresholds can be used to distinguish large metallic landmines. Large amounts of metallic clutter on the battlefield lead to extremely high false-alarm rates when EMI detectors are used to find small antipersonnel landmines. New detection capabilities improve the ability to better distinguish mines from clutter.

This approach is consistent with the handheld standoff mine detection system (HSTAMIDS) and the ground standoff mine detection system (GSTAMIDS). The new EMI techniques, when used with GPR techniques, may provide keys to providing substantive improvement in both handheld and vehicle-mounted mine detectors.

WORLDWIDE TECHNOLOGY ASSESSMENT

Austria	●●●●	Bulgaria	●	Canada	●●	China	●
Denmark	●●	Egypt	●	Finland	●	Germany	●●●●
India	●	Italy	●	Japan	●●	Pakistan	●
South Africa	●●	Spain	●	Sweden	●	UK	●●●
United States	●●●●						

Legend: Extensive R&D ●●●● Significant R&D ●●● Moderate R&D ●● Limited R&D ●

The high interest in humanitarian demining has led to renewed interest and investment in EMI detectors throughout the world. A new Australian EMI approach for military mine detectors has spurred interest in the use of EMI detectors against low-metal content antipersonnel landmines. Austria, Germany, France, and the UK also make high-performance mine detectors. The NATO nations are now investigating the fusion of GPR technology with EMI threshold techniques for use as detectors of both metallic and plastic mines.

Emerging research currently being conducted by multi-university research initiatives through the Army Research Office has demonstrated marked improvements in the rejection of false alarms using time-domain and frequency-domain EMI techniques. Both of these techniques are being combined with advanced signal-processing techniques to produce receiver operating characteristic (ROC) curves that evidence major growth in the reduction of false alarms.

DATA SHEET III-17.8. SUPERCONDUCTING QUANTUM INTERFENCE DEVICES

Developing Critical Technology Parameter	SQUIDS are used together with signal-processing techniques to detect sea mines on the seabed or buried in the seabed. The distortion to the earth's magnetic field caused by metallic objects on or in the ocean floor is used to calculate the position of sea mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	The high sensitivity of the SQUID devices requires high platform stabilization and stabilization position information to accurately assess the presence of mines and clutter during detection sweeps.
Unique Software	Special software is being written to identify anomalies detected by these extremely sensitive detectors.
Technical Issues	The calculation of target images is dependent on three-axis platform stabilization and corrections, as well as upon relative platform position.
Major Commercial Applications	None identified.
Affordability	The development of extremely sensitive superconducting sensors for an ocean environment is expensive. The development risk is offset by the potential payoff for operations to be conducted in the littorals.

RATIONALE

Mines on and buried in the ocean floor are difficult to detect. These mines, particularly when deployed in coastal waters, are a great threat to amphibious vehicles. SQUIDS combined with advanced sonar techniques could be used to find mines or clear lanes for operations to be conducted in coastal areas.

WORLDWIDE   TECHNOLOGY   ASSESSMENT

United States   ●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States is the leader in this technology with a moderate R&D effort.

DATA SHEET III-17.8. REACTIVE MUNITIONS

Developing Critical Technology Parameter	Projectiles either lined with pyrophoric materials or composed of pyrophoric materials can be used to initiate burning as they pass through a target. In the case of both land and sea mines, the burning can lead to total consumption of the explosive charge or to detonation. The critical issues are the projectile velocities needed to effect penetration and the type of pyrophoric material capable of initiating burning in explosives at the chosen velocities.
Critical Materials	At high velocities, a number of materials are known to react pyrophorically with explosives. The use of these materials as liners could make the projectiles less costly and better suited to existing canons, launchers, etc.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	The pyrophoric reaction must guarantee that the target mines are consumed either through detonation or burning. This is not a trivial issue in that it requires that some minimal energy be deposited in the target explosive during the transit of the high-speed projectile.
Major Commercial Applications	None identified.
Affordability	This approach must be tied to a detection/homing system with a low false-alarm rate. High false-alarm rates will make the system extremely expensive.

RATIONALE

Current line charge and evolving explosive net deployments cause operational pauses during assaults on and through beach areas. Because of the heavy concentration of enemy fire on these areas, it is extremely important that minefields and obstacles be breached rapidly. The development of reactive munitions for mine neutralization is a high-payoff approach for enabling precision-guided submunitions to rapidly clear lanes through beaches with mines and other obstacles.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States ●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States is the leader in this technology with a moderate R&D effort.

DATA SHEET III-17.8. HIGH-PRESSURE WATER JETS

Developing Critical Technology Parameter	High-pressure (2,000–100,000 psi) water jets fired at mines can rapidly penetrate the mine case and cause destruction of the mine main explosive charge. Devices that can be backpack-mounted have been demonstrated for use by dismounted troops against antipersonnel land mines. Larger devices that are mounted on tactical and amphibious vehicles for use against antitank and sea mines have also been demonstrated.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Technical Issues	The type and thickness of the mine casing determines the stagnation pressures necessary for penetration, as well as the total amount of fluid necessary to remove the mine main explosive charge.
Major Commercial Applications	Water jets are commercially used in agricultural, mining, and cutting applications.
Affordability	Small backpack systems to neutralize individual mines are relatively inexpensive. Larger water jets need to be mounted on amphibious or remotely controlled underwater vehicles and are moderately expensive.

RATIONALE

Many operational environments require that individual mines and unexploded ordnance be cleared or neutralized individually. High-pressure water jets are an ideal method for quickly neutralizing these devices without actuating the main explosive charge. The high stagnation pressures cause mechanical relief on a time scale shorter than explosive induction times, even for primary explosives. Underwater and explosive ordnance disiposal applications are ideally suited to this technology approach because they minimize collateral damage during the neutralization process.

WORLDWIDE TECHNOLOGY ASSESSMENT

Germany	●●●	Japan	●●	South Africa	●●	Sweden	●●
UK	●●●●	United States	●●●●				

Legend: Extensive R&D ●●●●   Significant R&D ●●●   Moderate R&D ●●   Limited R&D ●

Although water jets are commercially available throughout the world for agricultural, mining, and cutting applications, the principal military focus of their use has been for explosive ordnance disposal. The UK has long used this technology to neutralize terrorist devices. The UK and the United States are leaders in this technology with extensive R&D, followed by Germany with significant R&D.

DATA SHEET III-17.8. PRECISION-GUIDED SUBMUNITIONS

Developing Critical Technology Parameter	The use of line charges and distributed explosive arrays deployed from LCACs is not a viable long-term solution for rapid assaults both on the beach and in the beach exit zone. Precision-guided submunitions are being investigated as an alternative method for rapidly breaching mine areas in these beach areas. The approach requires airborne targeting, homing, and lethal payloads in submunitions.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	The complex systems must be matured in simulation before expensive field testing.
Unique Software	New software must be developed for mine targeting.
Technical Issues	Although current systems can deliver weapons to a specified basket, submunition target detection and target homing must be developed and demonstrated. In addition, a high P_k greater than 0.95 must be developed and demonstrated.
Major Commercial Applications	None identified.
Affordability	The development cost of this system will be expensive.

RATIONALE

Current line charge and evolving explosive net deployments cause operational pauses during assaults on and through beach areas. Because of the heavy concentration of enemy fire on these areas, it is extremely important that minefields and obstacles be breached rapidly. Submunitions that rapidly create breaches in enemy minefields in advance of operations through the beach area reduce the number of friendly casualties and help ensure success in achieving overall timelines and force objectives.

WORLDWIDE TECHNOLOGY ASSESSMENT

United States	●●

Legend:	Extensive R&D ●●●●	Significant R&D ●●●	Moderate R&D ●●	Limited R&D ●

The United States is the only country known to be pursuing this long-term approach for rapid breach assaults.